LOGICAL DESIGN FOR FAST SERIAL COMPUTER

TECHNICAL REPORT NO. ESD-TR-65-81

JULY 1965

H. B. Enderton

Prepared for

DIRECTORATE OF COMPUTERS
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

Project 508

Prepared by

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ABSTRACT

The detailed logical design is given for a serial digital computer using a 0.5-microsecond magnetic memory, 100-mc logical circuits, and one-word delay lines. The computer performs most instructions in 1 microsecond. A list is given of the amount of hardware used.

REVIEW AND APPROVAL

This technical documentary report has been reviewed and is approved.

James A Mellin Major USAF

SEYMOUR JEFFERY
Major, USAF
Chief, Computer Division

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LOGICAL DESIGN FOR FAST SERIAL COMPUTER

SECTION I

INTRODUCTION

This report presents a design for a fast serial digital computer. This design was made to answer the questions:

What is currently feasible for this type of computer?

What characteristics might such a machine have?

The logic circuits used are the 100 mc circuits developed at MITRE. The memory is a parallel magnetic storage unit with 0.5-μs cycle time. Ten delay lines (developed at MITRE) are used for one-word registers.

In Sections II and III, the performance of the computer and the amount of hardware required are summarized. The remainder of the report is devoted to the detailed design.

SECTION II

PERFORMANCE

Assume a 100-mc clock rate and a 0.5-μs memory. Each word consists of 24 usable bits including sign. The time required for typical instructions is:

Add	1 μs
Shift	1 μs (either direction, any amount)
Multiply	6.75 μs
Divide	6.75 μs
Normalize	1.25 μs (transfers control if number is zero)

All other built-in instructions require 1 μs (load, store, etc.).

Floating point operations are not built-in, but can be done by subroutine. Such subroutines have been written with the following average times:

Floating add	24 μs
Floating multiply	15 μs
Floating divide	25 μs

Three index registers are provided. A program interrupt feature is included. A parity bit is generated for each word stored in memory. When a word is read from memory, its parity is checked.

There is a single channel which can be used for both input and output, but not both simultaneously. Once initiated, an I/O operation can transfer any given number of words between the I/O device and the memory without attention from the main program. When the I/O operation is complete, a program interrupt signal is generated.

SECTION III

COST

Table I contains the number of circuit packages used for each type of logic circuit.

Table I

Circuit Packages

Circuit	Figure No. in Appendix	AND Gates	OR Gates	FF	I & A*
A register	5-8	65	4	10	1.5
Arithmetic	9-11	34	3	6	0
Q register	12-15	46	2	5	1
B register	16	12	2	3	1
Shift counter	17-18	41	3	5	1.5
PC	19-20	20	2	3	0.5
Index regs, G	21-24	77	3	16	2
MAS, MA	25-26	56	0	30	3
MIO, MB	27-32	199	5	56	15
PI	33-34	27	2	7	1
IR, decoder	35-36	56	2	12	5.5
Timing	37-40	45	1	15	26.5
I/O	41-47	97	4	27	3.5
GATES		775	33	195	62
PKGS		388	33	195	62
Logic packages	678				
Clock pulse packages	88				
TOTAL	766 packages				
Other: 10 delay lines with drive amplifiers and phase inverters. 1 memory, 0.5-μs cycle, 25 bits, up to 32 K.					

*I represents inverting amplifiers

A represents noninverting amplifiers

SECTION IV

ORGANIZATION

The block diagram of the fast serial digital computer is shown in Figure 1. The memory is connected to two registers of flip-flops, MB and MIO. The MIO is also a shift register, and it is here that the parallel to serial conversion takes place.

The A register is the main arithmetic register. The Q register is used in multiply and divide. Both are delay lines, as are the three index registers, XRA, XRB, and XRC.

The MAS and MA are flip-flop registers used for the memory address. The program counter (PC) is a delay line.

The I/O circuitry includes three delay lines, the work counter (WC), address counter (AC), and word buffer (WB). The device buffer (DB) is an eight-bit flip-flop register.

Word format is as follows:

Data:	Bits 0-22:	magnitude
	Bit 23:	sign (zero for plus)
	Bit 24:	guard bit (not usable).
	Ones complement is used for negative numbers.	
Instructions:	Bits 0-14:	address
	Bits 15-17:	index tag
	Bits 18-23:	operation code
	Bit 24:	guard bit.

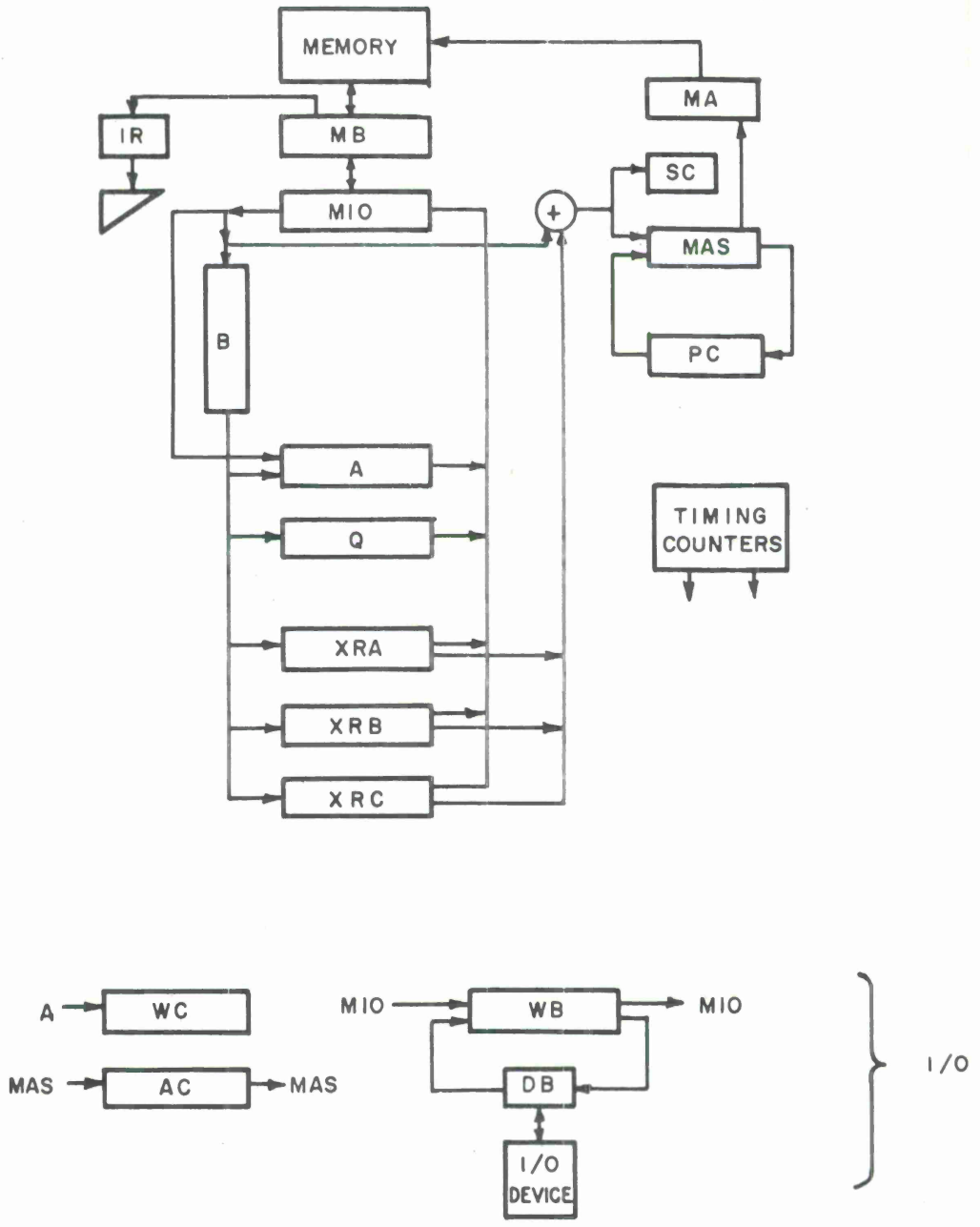


Figure 1. Fast Serial Digital Computer

In memory storage the guard bit is replaced by a parity bit.

One word time is 250 ns. Normally an instruction requires four word times (1 μs), i.e., two memory cycles. These four word times are designated T1 to T4. Within each word time there are 25 bit times, designated F_0 to F_{24}. The bit time (Ti and F_j) is abbreviated Ti_j in the mechanization equations.

In preparation for starting a computer program, a master reset signal is provided. This signal:

(1) Clears I/0 control flip-flops;

(2) Clears AC, WC, CC, and DB;

(3) Clears λ and injects HLT into IR;

(4) Sets the program interrupt controls to accept only the "input complete" interrupt, and clears PI, IC.

(It also destroys the contents of most registers by suspending the t pulses.) A console signal can then set the input status FF (IS) to initiate an input operation. This operation will fill memory, starting with location 0, until an end-of-file signal sets PI, IC. This causes the computer to execute the instruction in location 1.

Instruction List

LDX	Load index register
LDQ	Load Q register
CLA	Clear and add into A
CLS	Clear and subtract
CAM	Clear and add magnitude
SHL	Shift left
SHR	Shift right
CYR	Cycle right
NMT	Normalize and transfer
NEG	Complement A
LGS	Logical sum
LGM	Logical multiply
STA	Store A
STQ	Store Q
STX	Store index
STZ	Store zero
ADD	Add
SUBT	Subtract
ADM	Add magnitude
SBM	Subtract magnitude
MLY	Multiply
DIV	Divide
TRU	Transfer unconditionally
TRN	Transfer if negative
TRP	Transfer if positive
TRZ	Transfer if zero
TROV	Transfer if overflow
TRX	Transfer and decrement index
TSX	Transfer and set index
RPI	Read program interrupt requests
SPI	Set program interrupt controls
SIO	Start input/output
HLT	Halt
NOP	No operation

Memory Timing

	Memory	PC/MAS
Normal		
T3	Read data	MAS → PC if branch
T4	Write data	PC → MAS
T1	Read instruction	PC+1 → PC
T2	Write instruction	Index into MAS
Program Interrupt		
T3	Read data	
T4	Write data	0 → MAS
T1	Clear 0	PC → MIO
T2	Write PC	1 → MAS
T1	Read instruction in 1	PC+1 → PC
T2	Write instruction	Index into MAS
I/O Cycle		
T3	Read data	
T4	Write data	AC → MAS
T1	Read I/O word	
T2	Write I/O word	PC → MAS
T1	Read instruction	PC+1 → PC
T2	Write instruction	Index into MAS

SECTION V

CIRCUIT CHARACTERISTICS

The timing assumption is as follows:

For any signal subject to change, at least every fourth gate must be an AND gate with a clock pulse input. (An exception is the timing levels, for which special methods are used.) The typical configuration is shown in Figure 2.

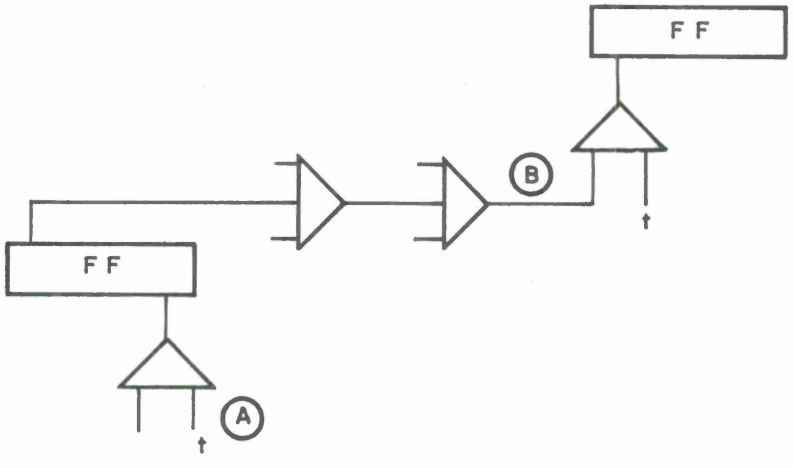


Figure 2. Typical Timing Circuit Configuration

For example if

(1) the clock pulse has a rise time of 1 ns;

(2) the logic circuits have rise and fall times of 2 ns; and

(3) the logic circuits have propagation delays of 2 ns;

then we have the situation in Figure 3.

Figure 3. Signal Propagation Time

The level at B must fall before the pulse at B rises. Thus there is only 0.5 ns available in the above situation for point-to-point propagation, assuming a 100 mc clock rate.

But the assumptions are only a crude approximation to the actual characteristics of the logic circuits. Only a detailed study of the timing situation will determine the maximum permissible clock rate.

The maximum fan-out is six. There is the possibility that this is overly conservative, and that in fact a fan-out of eight (for levels) could be used. The fan-out restriction implies that certain circuits must be duplicated. Duplication is often preferable to using amplifiers, which increase the number of stages of delay.

SECTION VI

MECHANIZATION EQUATIONS

The notation used is: When the conditions to the left of the colon are satisfied, then the action specified on the right side is taken. The index of abbreviations is in Section VII.

Memory

1. $(T1_{23})(SI')$: [0 => MIO]

   $(T1_{23})(SI)$: [0 => MB]

   $(T1_{24})(SI')$: [MB => MIO]

   $(T1_{24})(SI)$: [MIO => MB]

   $(T1_{24})$: [1 → WR] [0 → SI] Rewrite instruction

2. $(T2_{23})$: [0 => MA]

   $(T2_{24})$: [MAS => MA] [1 → RD] [0 => MB] Read data

3. $(T3_{23})(SI')$: [0 => MIO]

   $(T3_{24})(SI')$: [MB => MIO]

   $(T3_{24})$: [1 → WR] [0 → SI] Rewrite data

4. $(T4_{23})(\lambda')$: [0 => MA]

   $(T4_{24})(\lambda')$: [MAS => MA] [1 → RD] [0 => MB] Read Instruction

Instruction Access

1. $(T4_{0-14})(IIC')$: [PC → MAS]

2. $(T4_{24})(IIC')(\lambda')$: [1 → IPC]

3. $(T2_{0-14})(IIC')$: [Index adder → MAS]

4. $(T2_{23})(IIC')$: $[MB_{18-23} \Rightarrow IR]$ Double-line

Note: IIC = IOF + PI + HLT.

Program Interrupt

1. $(T3_{24})(IOF')(IPI')\left\{(PI, IC) + (\Sigma PI)(PIC)\right\}$: [1 → IPI] [1 → PIC]

2. $(PI)(T4_{0-14})$: [0 → MAS]

3. $(PI)(T4_{24})$: [1 → SI]

4. (PI)(TI) : [PC → MIO]

5. $(PI)(T2_{22})$: [1 → λ]

   $(PI)(T2_{23})$: [1 → MAS_0] [NOP => IR] [1 → T] [0 → λ]

   $(PI)(T2_{24})$: [0 → PIC]

Note: PI = (IPI)(PIC)

Note: The instruction in location 1 should be a TRU, since the above does not alter PC. The instruction whose address is stored in location 0 has not yet been executed.

Input

1. $(PI')(IDR)(T2_{23})$: [1 → ICF]

2. (ICF)(T3)(CCF) : [DB → WB] [0 → DB]

3. $(ICF)(T3_{23})$: [CC+1 → CC] [0 → IDR] [0 → ICF]

   $(ICF)\ (T3_{23})(CC=2)$: [1 → IF] [1 → IAC, DWC]

Output

1. $(PI')(ODR)(T2_{23})$: [1→OCF]

2. (OCF)(T3)(CCF) : [WB → DB]

3. $(OCF)(T3_{23})$: [CC+1 →CC] [0 → ODR] [0 →OCF]

   $(OCF)(T3_{23})(CC=2)(WC\neq 0)$: [1 →OF]

   $(OCF)(T3_{23})(CC=2)(WC=0)$: [1 → PI, OC] [0 → OS]

Note: CC counts modulo 3.

$CCF = (CC=O)(F_{0-7}) + (CC=1)(F_{8-15}) + (CC=2)(F_{16-23})$

Note: Device sets IDR or ODR.

Clearing IDR or ODR allows device to proceed to fill or read DB.

Note: DB shift signal = (T3)(CCF)(ICF + OCF).

Input/Output

1. $(IOF)(T4_{0-14})$: [AC → MAS]

2. $(IF)(T4_{24})$: [1 → SI]

3. (IF)(T1) : [WB → MIO]

4. $(IOF)(T2_{0-14})$: [PC → MAS]

5. (OF)(T2) : [MIO → WB]

6. $(IOF)(T2_{22})$: [1 → λ]

   $(IOF)\ (T2_{23})(HLT')$: [NOP → IR]

7. $(IOF)(T2_{23})$: [1 → T] [0 → λ]

   $(IOF)(T2_{24})$: [0 → IOF]

$(IF)(T2_{24})(WC=O)$: [0 → IS] [1 → PI, IC]

$(OF)(T2_{24})$: [1 → IAC, DWC]

$(IOF)(T2_{24})(HLT')$: [1 → IPC]

Miscellaneous

1. $(T4_{24})(\lambda')$: [0 → IMS]
2. (T4) : [MIO → B] unless specifically overruled
3. $(T1_{24})$: [0 → SN]
4. (F23) : [0 → SUB]
5. $(T4)(\lambda)$: [B → B]

Instructions

LDX

1. (T1) : [B → XRG]

LDQ

1. (T1) : [B → Q]

CLA

1. (T1) : [B → A]

CLS

1. (T4) : [MIO' → B]
2. (T1) : [B → A]

CAM

1. $(MB_{23})(T4)$: [MIO' → B]
2. (T1) : [B → A]

SHL

1. $(T2_{24})$: [1 → SI]

2. (T3) : [A → MIO] [0 → A]

3. $(T3_{23})$: [1 → IMS]

4. (T4) : [SC-1 => SC]

5. (T4)(SC=0) : [0 → IMS]

6. (T4)(IMS') : [MIO → A]

SHR

1, 2, 4 as in SHL.

8. $(T4_{0-23})$(SC=0) : [1 → IMS]

9. (T1) : [MIO → A]

Note: Copies of sign enter from the left.

CYR

1, 2, 4, 8, 9 as above.

7. (T4) : [MIO → MIO]

Note: The three above instructions shift one place more than the number in the address field.

NMT Normalize and Transfer

1. $(T2_{24})$: [-0 => SC] [1 → SI]

2. $(T3_{0-14})(A_Z)$: [MAS → PC]

3. (T3) : [A → MIO]

4. $(T3_{0-22})(A \neq A_{SN})$: [-0 => SC]

   $(T3_{0-22})(A = A_{SN})$: [SC-1 => SC]

5. $(T3_{23})$: [1 → IMS]

6. $(T4_{0-4})(\lambda')$: [SC → A] [SC' → SC]

   $(T4_{5-24})(\lambda')$: [1 → A]

7. $(T4_{22})(\lambda')$: [1 → λ]

8. $(T4_{24})$(SC=0) : [0 → IMS]

   (T4)(λ)(SC=1) : [0 → IMS]

9. (T4)(λ) : [SC-1 => SC]

10. (T4)(IMS) : $[MIO_{23} \rightarrow Q]$

    (T4)(IMS') : [MIO → Q]

11. $(T4_{22})(\lambda)$: [0 → λ]

Note: A contains the negative of the number of shifts. The normalized number (if non-zero) is in Q.

NEG

1. (T3) : [A' → A]

LGS Logical Sum

1. (T1) : [A ∨ B → A] (inclusive or)

LGM Logical Multiply

1. (TI) : [A · B → A]

STA Store A

1. ($T2_{24}$) : [1 → SI]

2. (T3) : [A → MIO]

3. ($T3_{23}$) : [0 => MB]

4. ($T3_{24}$) : [MIO => MB]

STQ Store Q

1, 3, 4 as above.

2. (T3) : [Q → MIO]

STZ Store Zero

1, 3, 4 as above

2. (T3) : [0 → MIO]

STX Store Index

1, 3, 4 as in STA.

2. (T3) : [XRG → MIO]

ADD

1. ($T4_{24}$) : [A_{SN} → SN]

2. (T1 + T2) : [A ⊕ B → A] Arithmetic sum

3. ($T2_{23}$)(SN = B_{SN} ≠ A ⊕ B) : [1 → OV]

SUBT

0. (T4) : [MIO' → B]

1, 2, 3 as above.

ADM

0. (MB_{23})(T4) : [MIO' → B]

1, 2, 3 as above.

SBM

0. (MB_{23}')(T4) : [MIO' → B]

1, 2, 3 as above.

MLY

1. $(T3_{23})(A_{SN} \neq MB_{23})$: [1 → SN]

   $(T3_{23})$: [-0 => SC]

2. (T4)(λ') : [0 → A]

   (TR)(λ')(A_{SN}') : [A → Q]

   (T4)(λ')(A_{SN}) : [A' → Q]

   (T4)(λ')(MB_{23}) : [MIO' → B]

3. $(T4_{22})(A_Z')$(λ') : [1 → λ]

   $(T4_{23})$: [SC-1 => SC]

   $(T4_{22})$(SC = 23) : [0 → λ]

4. (λ)(F_{0-21}) : [Q_T → Q]

   (λ)$(F_0)(Q_0)$: [A ⊕ B → Q_+]

$(\lambda)(F_0)(Q_0')$: $[A \rightarrow Q_+]$

$(\lambda)(F_0')(Q_0)$: $[A \oplus B \rightarrow A_T]$

$(\lambda)(F_0')(Q_0')$: $[A \rightarrow A_T]$

$(\lambda)(F_{22})$: $[Q_+ \rightarrow Q]$

$(\lambda)(F_{23-24})$: $[0 \rightarrow Q]$

$(\lambda)(F_{24})$: $[Q_T \rightarrow Q_0]$ (normal)

5. $(T1)(SN)$: $[A' \rightarrow A]$ $[Q' \rightarrow Q]$

Note: During (MLY)(λ), the normal $Q_T \rightarrow Q_0$ is suppressed.

DIV

1. $(T3)(A_{SN}')$: $[A' \rightarrow A][Q' \rightarrow Q]$

$(T3_{23})(A_{SN} \neq MB_{23})$: $[1 \rightarrow SN]$

$(T3_{23})$: $[-0 \Rightarrow SC][0 \rightarrow Q_+]$

2. $(\lambda')(MB_{23})(T4)$: $[MIO' \rightarrow B]$

3. $(\lambda')(T4_{22})$: $[1 \rightarrow \lambda]$

$(T4_{23})$: $[SC-1 \Rightarrow SC]$

$(T4_{22})(SC = -23)$: $[0 \rightarrow \lambda]$

$(\lambda)(F_{24})(A_+')$: $[1 \rightarrow OV]$ Abort if

$(\lambda)(F_{22})(OV)$: $[0 \rightarrow \lambda]$ overflow

4. $(\lambda)(SUB)$: $[A \oplus B \rightarrow A_+]$

$(T4)(SUB')$: $[A \rightarrow A_+]$

5. $(T4_0)(SC \neq -23)$: $[Q_H \rightarrow A]$

$(T4_{1-24})(SC \neq -23)$: $[A_+ \rightarrow A]$

6. $(T4) : [Q \rightarrow Q_+]$

$(T4_0) : [SUB \rightarrow Q]$

$(T4_{1-24}) : [Q_+ \rightarrow Q]$

7. $(T4_{24})(B \leq |A|) : [1 \rightarrow SUB]$

8. $(SC = -23)(SUB) : [A \oplus B \rightarrow A]$

$(SC = -23)(SUB')(\lambda) : [A \rightarrow A]$

9. $(T1)(SN') : [Q' \rightarrow Q]$

Note: Remainder in A is negative.

TRU

1. $(T3_{0-14}) : [MAS \rightarrow PC]$

TRN

1. $(T3_{0-14})(A_{SN}) : [MAS \rightarrow PC]$

TRP

1. $(T3_{0-14})(A_{SN}') : [MAS \rightarrow PC]$

TRZ

1. $(T3_{0-14})(A_Z) : [MAS \rightarrow PC]$

TROV

1. $(T3_{0-14})(0V) : [MAS \rightarrow PC]$

2. $(T3_{24}) : [0 \rightarrow 0V]$

TRX

1. $(T3_{0-14})(XRGZ') : [MAS \rightarrow PC]$

2. $(T3_{24})(XRGZ') : [1 \rightarrow DXRG]$

TSX

1. $(T3_{0-14})$: [MAS → PC] [PC → XRG]

RPI Read Program Interrupt Requests

1. $(T3_{0-4})$: [PIR → A] [0 → PIR]

2. $(T3_{5-24})$: [0 → A]

Note: No FF in PIR should be set during F_0 - F_4.

Last FF in PIR should not be set during F_0 - F_{22}.

SPI Set Program Interrupt Controls

1. $(T3_{24})$: $[MA_0 \rightarrow PIC]$ $[MA_1 \rightarrow IPI]$

Note: The effect of these controls is:

(IPI')(PIC) : Any interrupt will be recognized.

(IPI')(PIC') : Only PI, IC will be recognized.

(IPI)(PIC') : No interrupts will be recognized.

Note: After clearing IPI, at least one instruction is executed before the next interrupt is recognized.

SIO Start input/output

1. (T3) : [MAS → AC] [A → WC]

2. $(A_Z')(A_{SN})(T3_{23})$: [1 → OS] [1 → OF]

$(A_{SN}')(T3_{23})$: [1 → IS]

HLT Halt

1. $(T2_{23})$(Start Button) : [NOP = > IR]

Note: A program interrupt will also start machine.

SECTION VII

ABBREVIATIONS

The number in parentheses represents the most relevant illustration.

A, A_{SN}, A_T, etc.	(5).
AC.	Address counter.
ADD.	An instruction.
Add class.	ADD + SUBT + ADM + SBM (36).
ADM.	Add magnitude (instruction).
B, B_{SN}, B_{24}.	(16).
CAM.	Clear and add magnitude (instruction).
CC.	Character count (46).
CCF.	(46).
CLA.	Clear and add (instruction).
CLS.	Clear and subtract (instruction).
COA.	Complementary output amplifier (4).
CYR.	Cycle right (instruction).
DA.	Drive amplifier (4).
DB.	Device buffer (47).
DIV.	Divide (instruction).
DL.	Delay line (4).
DWC.	Decrease word count (45).
DXR(A).	Decrease index register (A) (21).
EOF.	End of file (34).
F_i.	Timing function number i (38).
FF.	Flip-flop (4).
G.	(22).
HLT.	Halt (instruction).

I.	Inverter (4).
IAC.	Increase address counter (44).
ICF.	Input control FF (41).
IDR.	Input data ready (41).
IF.	Input flag (41).
IIC.	Inhibit instruction control (35).
IMS.	Inhibit MIO shift (30).
IOF.	Input/output flag (41).
IP.	Input parity (31).
IPC.	Increase program counter (19).
IPI.	Inhibit program interrupt (33).
IR.	Instruction register (35).
IS.	Input status (42).
LDX.	Load index (instruction).
LDQ.	Load Q register (instruction).
LGM.	Logical multiply (instruction).
LGS.	Logical sum (instruction).
MA.	Memory address register (26).
MAS.	Memory address storage (26).
MB.	Memory buffer register (28).
MIO.	Memory input-output register (28).
MLY.	Multiply (instruction).
MRE.	Master reset signal.
NEG.	Negate (instruction).
NMT.	Normalize and transfer (instruction).
NOP.	No operation (instruction).
OCF.	Output control FF (41).
ODR.	Output data ready (41).

OF.	Output flag (42).
OP.	Output parity (31).
OS.	Output status (42).
OV.	Overflow (10).
PC.	Program counter (19).
PI.	Program interrupt level (33).
PIC.	Program interrupt control (33).
PIR.	Program interrupt register (34).
Q, Q_H, etc.	(12).
RD.	Read signal (29).
RPI.	Read program interrupt requests (instruction).
SBM.	Subtract magnitude (instruction).
SC.	Shift counter (17).
Shift.	SHL + SHR + CYR (36).
SHL.	Shift left (instruction).
SHR.	Shift right (instruction).
SI.	Strobe inhibit (32).
SIO.	Start input/output operation (instruction).
SN.	Sign (10).
SPI.	Set program interrupt controls (instruction).
STA.	Store A (instruction).
Store.	STA + STQ + STX + STZ (36).
STQ.	Store Q (instruction).
STX.	Store index (instruction).
STZ.	Store zero (instruction).
SUB.	Subtraction control (33).
SUBT.	Subtract (instruction).
t.	Clock pulse.

Ti.	Timing level (39).
TP.	Test parity (31).
TRN.	Transfer if A is negative (instruction).
TROV.	Transfer on overflow (instruction).
TRP.	Transfer if A is positive (instruction).
TRU.	Transfer unconditionally (instruction).
TRX.	Transfer and decrement index (instruction).
TRZ.	Transfer if A is zero (instruction).
TSX.	Transfer and set index (instruction).
WB.	Word buffer (43).
WC.	Word counter (45).
WCZ.	Word count is zero (45).
WR.	Write signal (32).
X.	Index signal (23).
XAD.	Index added to address (24).
XR(A)	Index register (A) (21).
XRG.	The index register specified by G.
α	Amplifier (2).
λ	(40).
$\emptyset$I	Phase inverter (4).
Σ PI	(34).

SECTION VIII

FLOATING POINT SUBROUTINES

We give programs for multiply, divide, and add.

FLOATING MULTIPLY SUBROUTINE

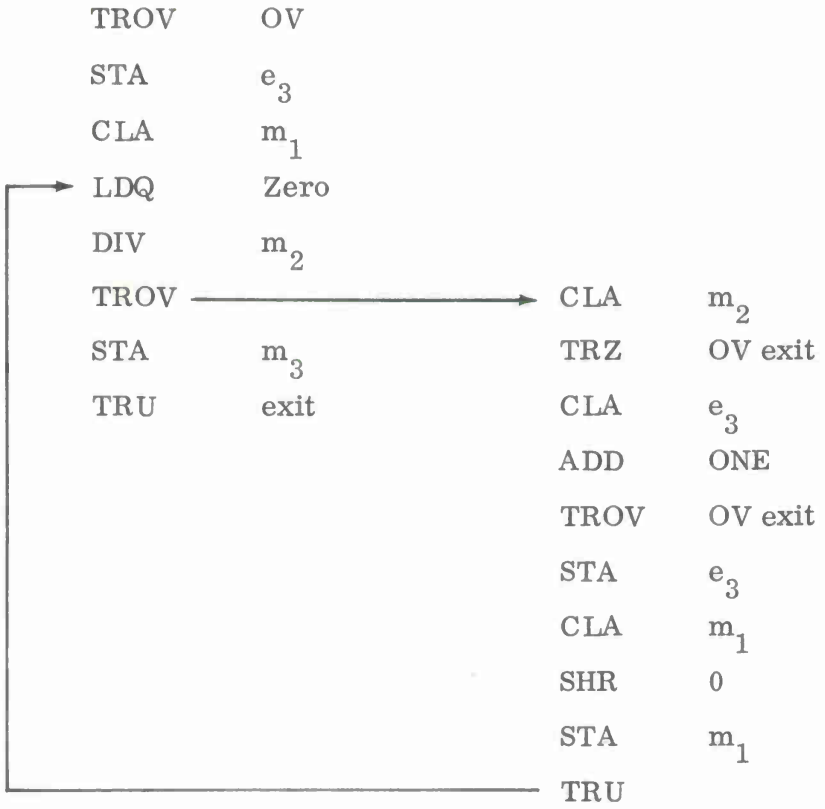
$$2^{e_3} m_3 = \left(2^{e_1} m_1\right)\left(2^{e_2} m_2\right)$$

```
        CLA     m1              Average time 15 μs
        MLY     m2
        NMT     Z
        STQ     m3
        ADD     e1
        ADD     e2
        STA     e3
        TROV    *+2
        TRU     exit
        TRN     OV exit
Z       STZ     m3              (Zero or
        CLA     min. exp.        underflow)
        STA     e3
        TRU     exit
```

FLOATING DIVIDE SUBROUTINE

$$2^{e_3} m_3 = \left(2^{e_1} m_1\right) / \left(2^{e_2} m_2\right)$$

```
        CLA     e1              Average time 25 μs
        SUBT    e2
```




```
OV      TRN   OV exit
        CLA   min. exp.
        STA   e3
        STZ   m3
        TRU   exit
```

FLOATING ADD SUBROUTINE

$2^{e_3} m_3 = 2^{e_1} m_1 + 2^{e_2} m_2$.

Average time 24 μs.

```
        CLA   e1
        STA   e3
```

```
XCH     CLA   e2
        STA   e3
```

```
        SUBT    e2
        TROV    α
        TRZ     No shft
        TRN     XCH
        SUBT    "22"
        TRP     No add
        ADD     SHR 21
        STA     * +2
        CLA     m2
        ---
AD      ADD     m1
β       TROV    OV
        NMT     Zero
        STQ     m3
        ADD     e3
        TROV    Zero
        STA     e3
        TRU     exit

α       TRN     No ADD
        CLA     e2
        STA     e3
NA      CLA     m2
        STA     m3
        TRU     exit
No Shft CLA     m2
        TRU     AD
```

```
        SUBT    e1
        SUBT    "22"
        TRP     NA
        ADD     SHR 21
        STA     * +2
        CLA     m1
        ---
        ADD     m2
        TRU     β

No Add  CLA     m1
        STA     m3
        TRU     exit

OV      SHR     0
        TRN     * +3
        LGS     Bit 23
        TRU     * +2
        LGM     Bit 23'
        STA     m3
        CLA     e3
        ADD     ONE
        TROV    OV exit
        STA     e3
        TRU     exit
Zero    CLA     min. exp.
        STA     e3
        STZ     m3
        TRU     exit
```

APPENDIX

ILLUSTRATIONS

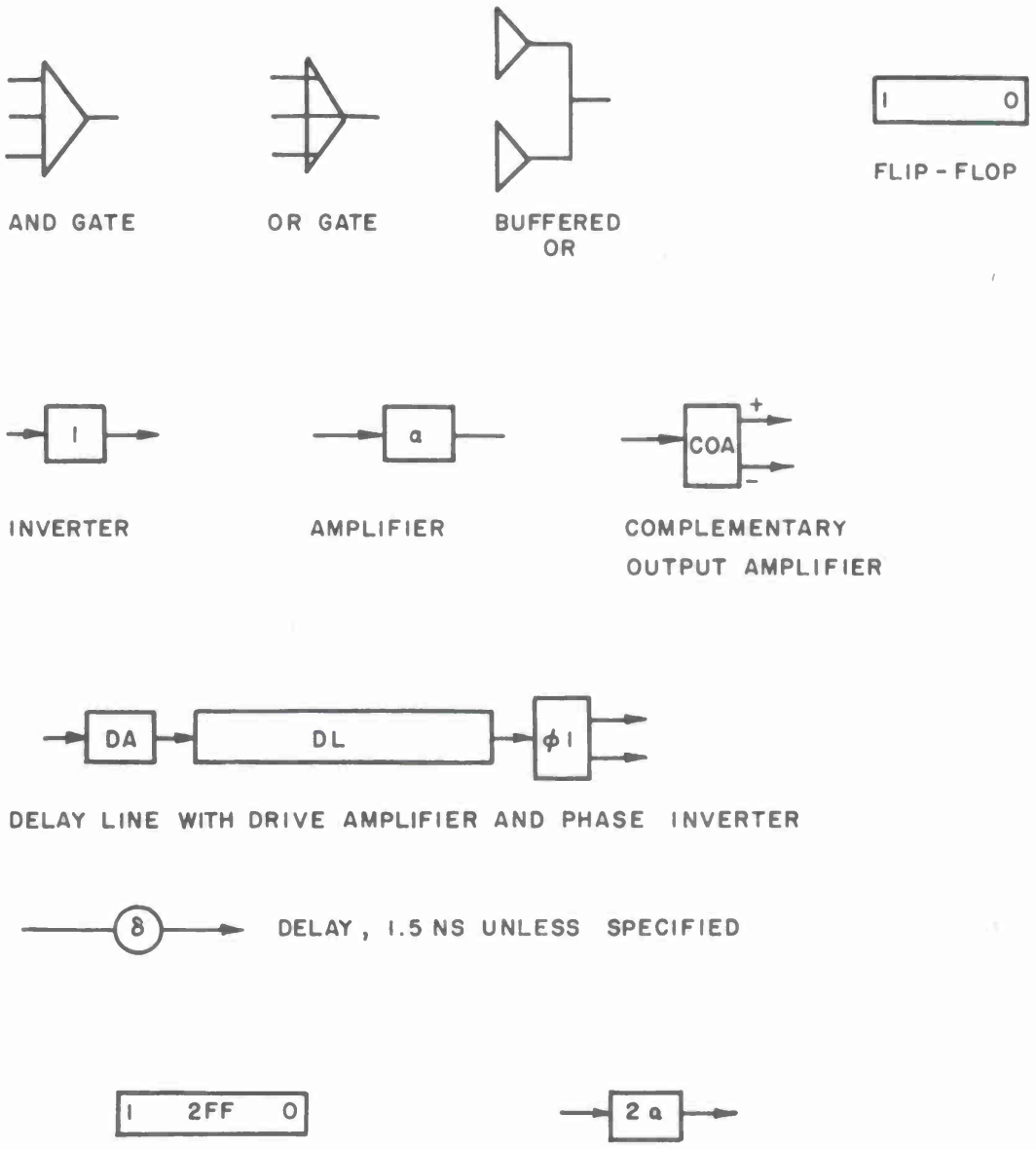
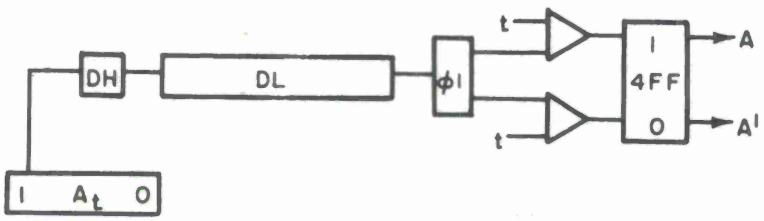
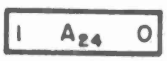


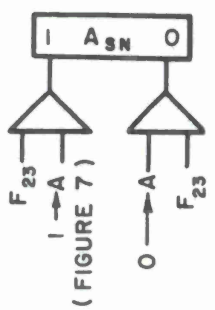
Figure 4. Notation for Logical Diagrams



SEE A_t GATING



SEE A GATING



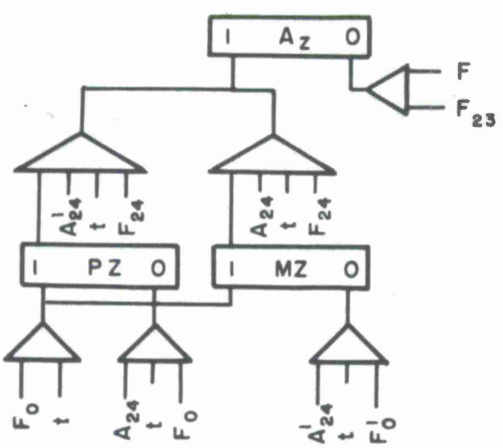


Figure 5. A Register

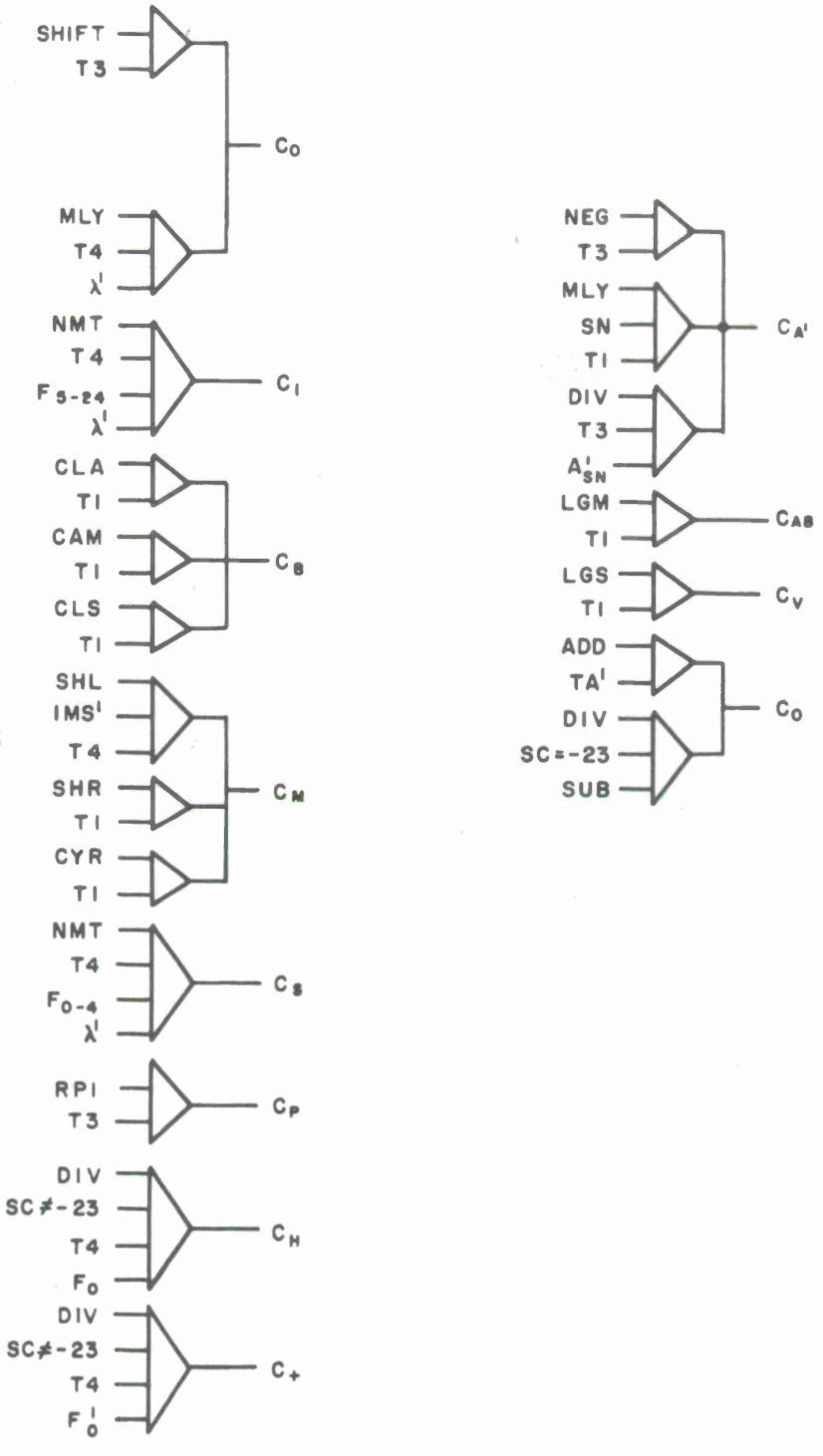


Figure 6. A Gates I

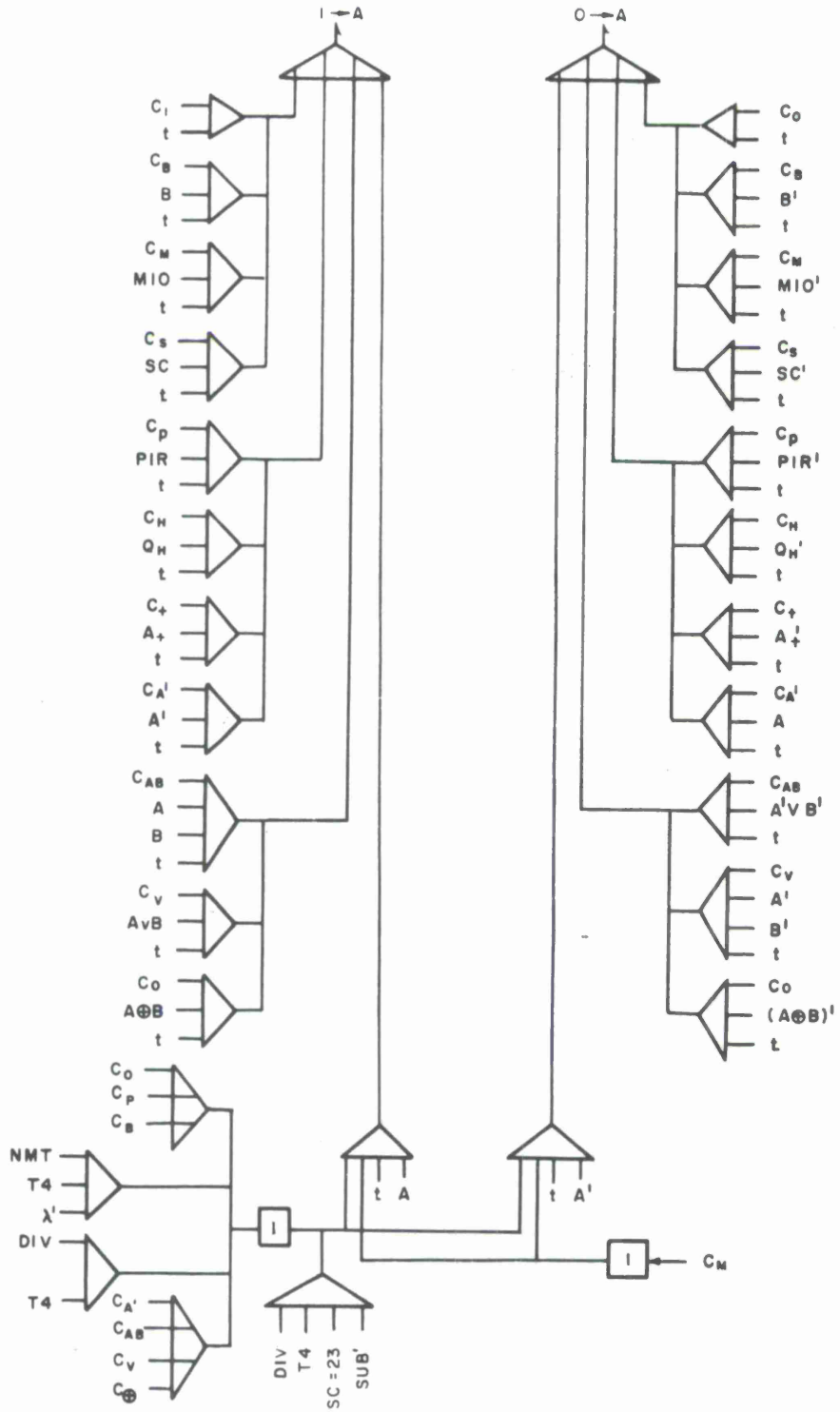


Figure 7. A Gates II

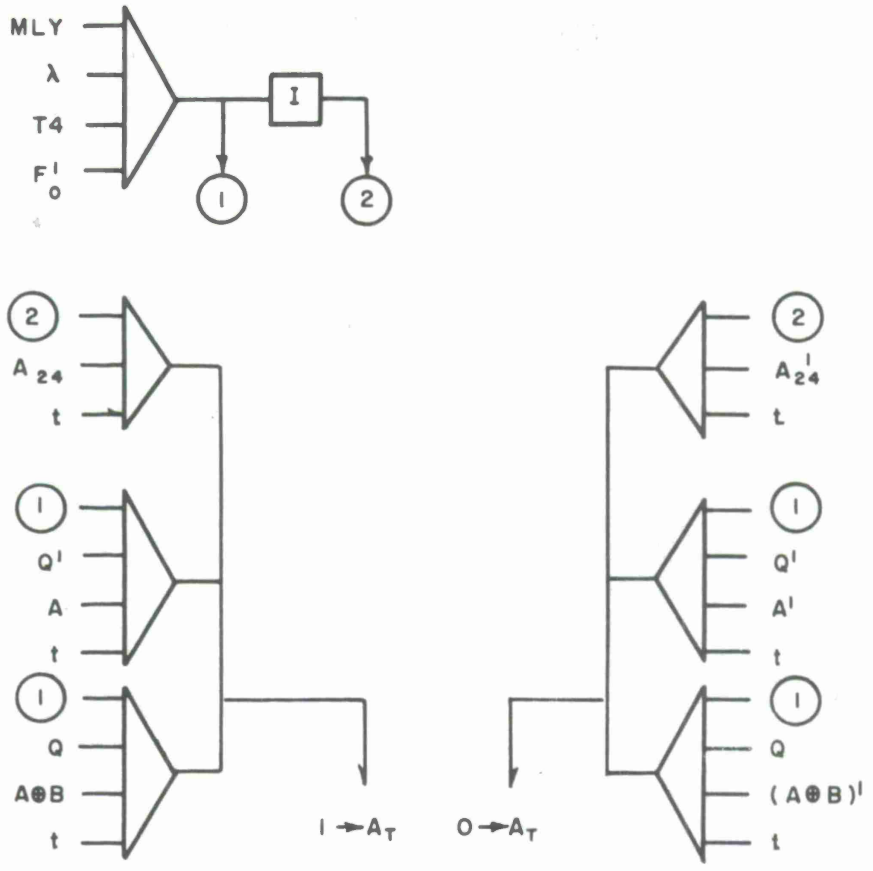
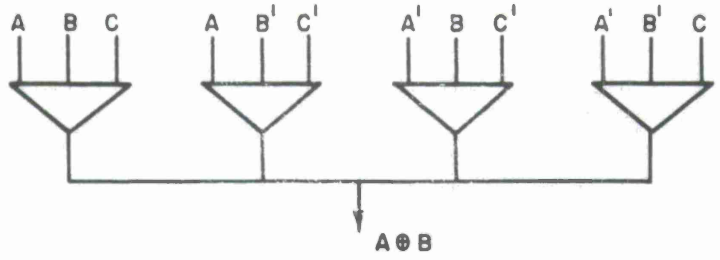
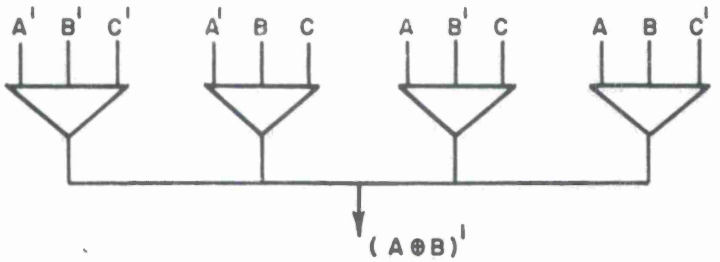
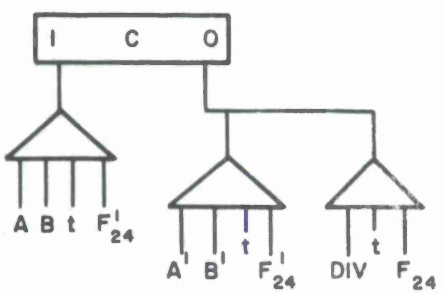
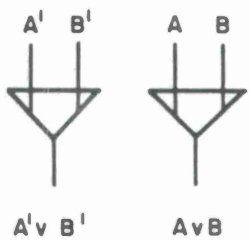


Figure 8. A_T Gating









A ⊕ B IS ARITHMETIC SUM

AvB IS LOGICAL SUM

Figure 9. Adder

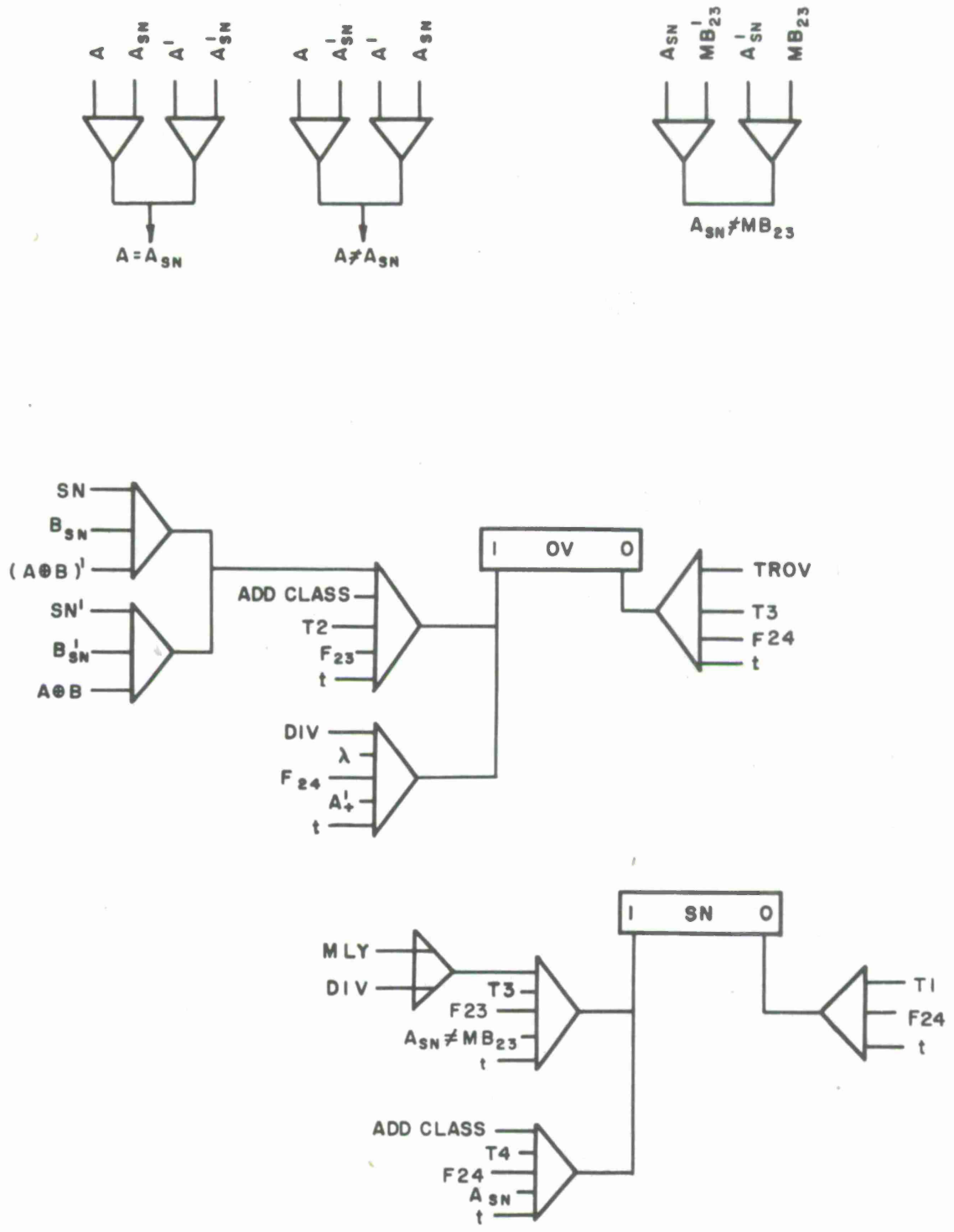


Figure 10. Miscellaneous Controls

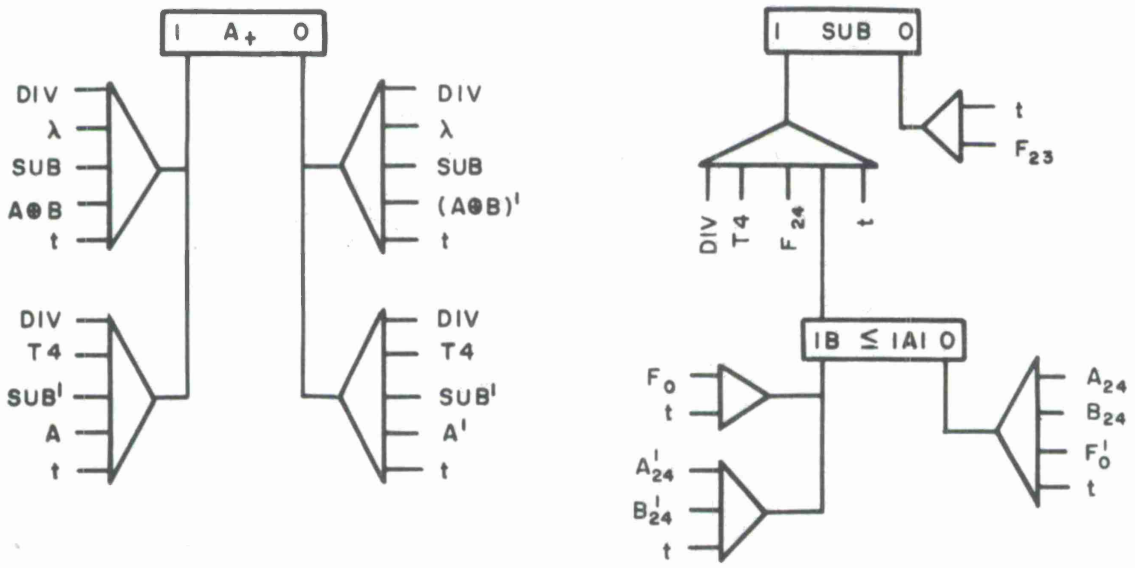


Figure 11. Divide Control

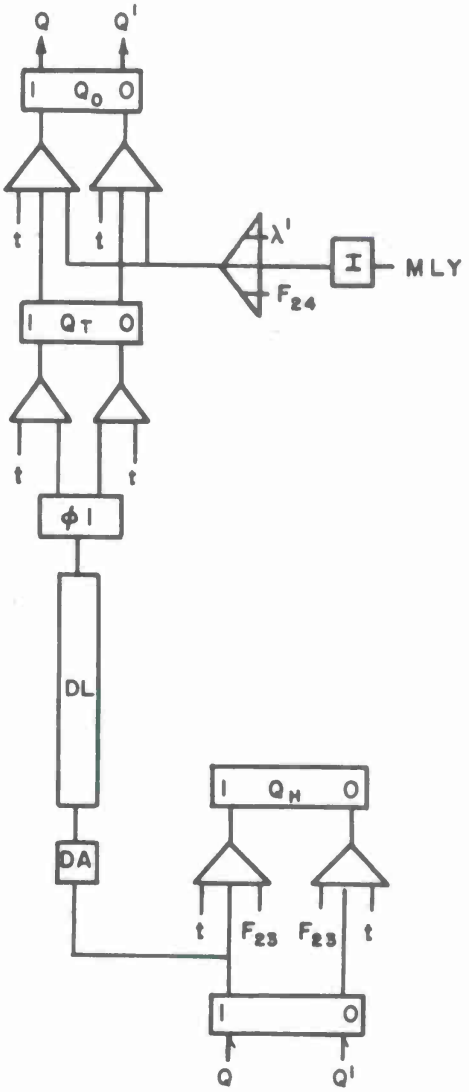


Figure 12. Q Register

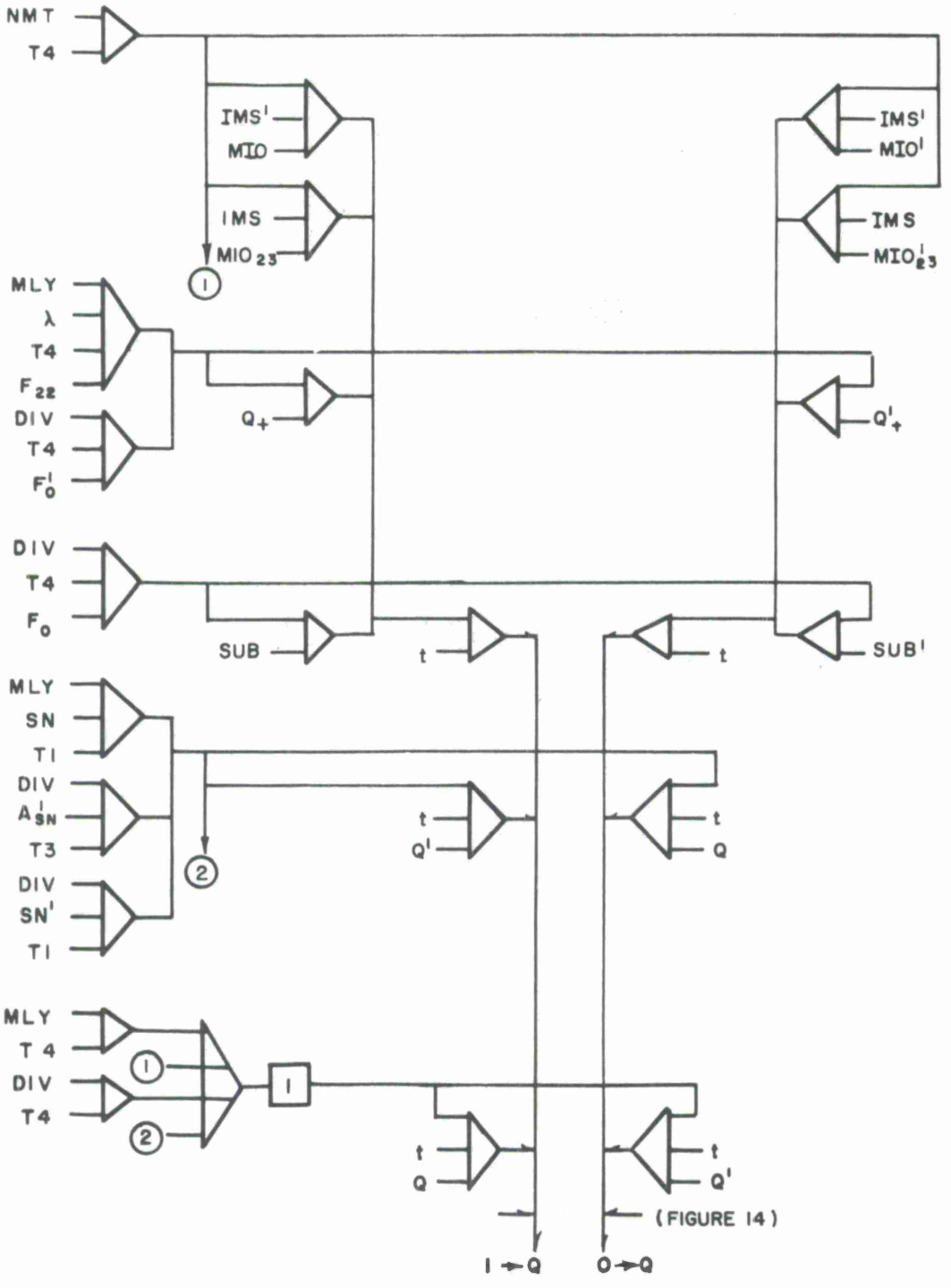


Figure 13. Q Gates I

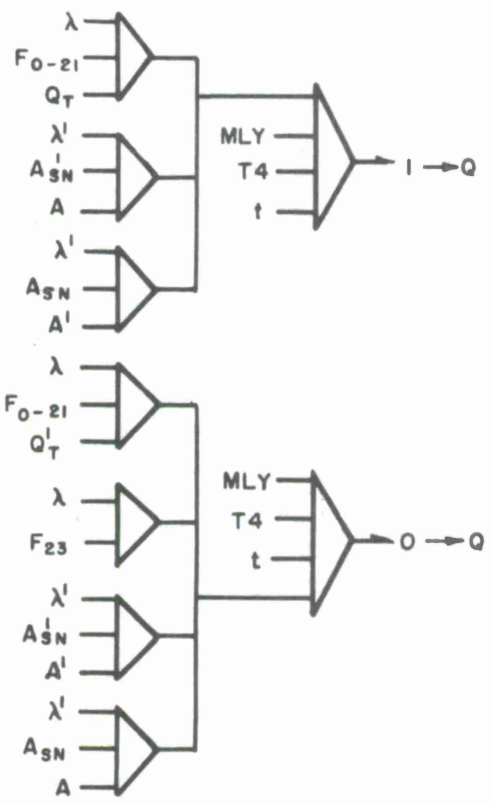


Figure 14. Q Gates II

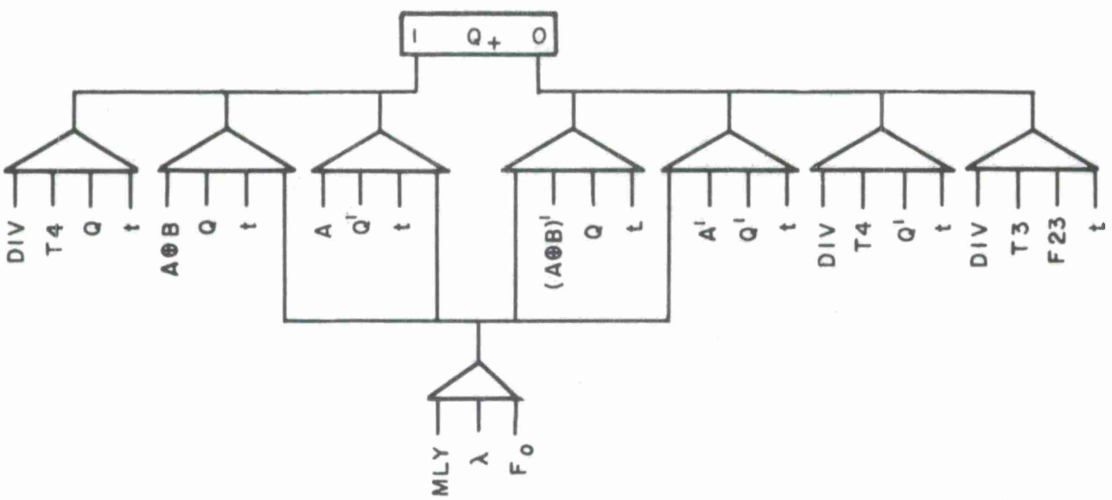


Figure 15. Q_+

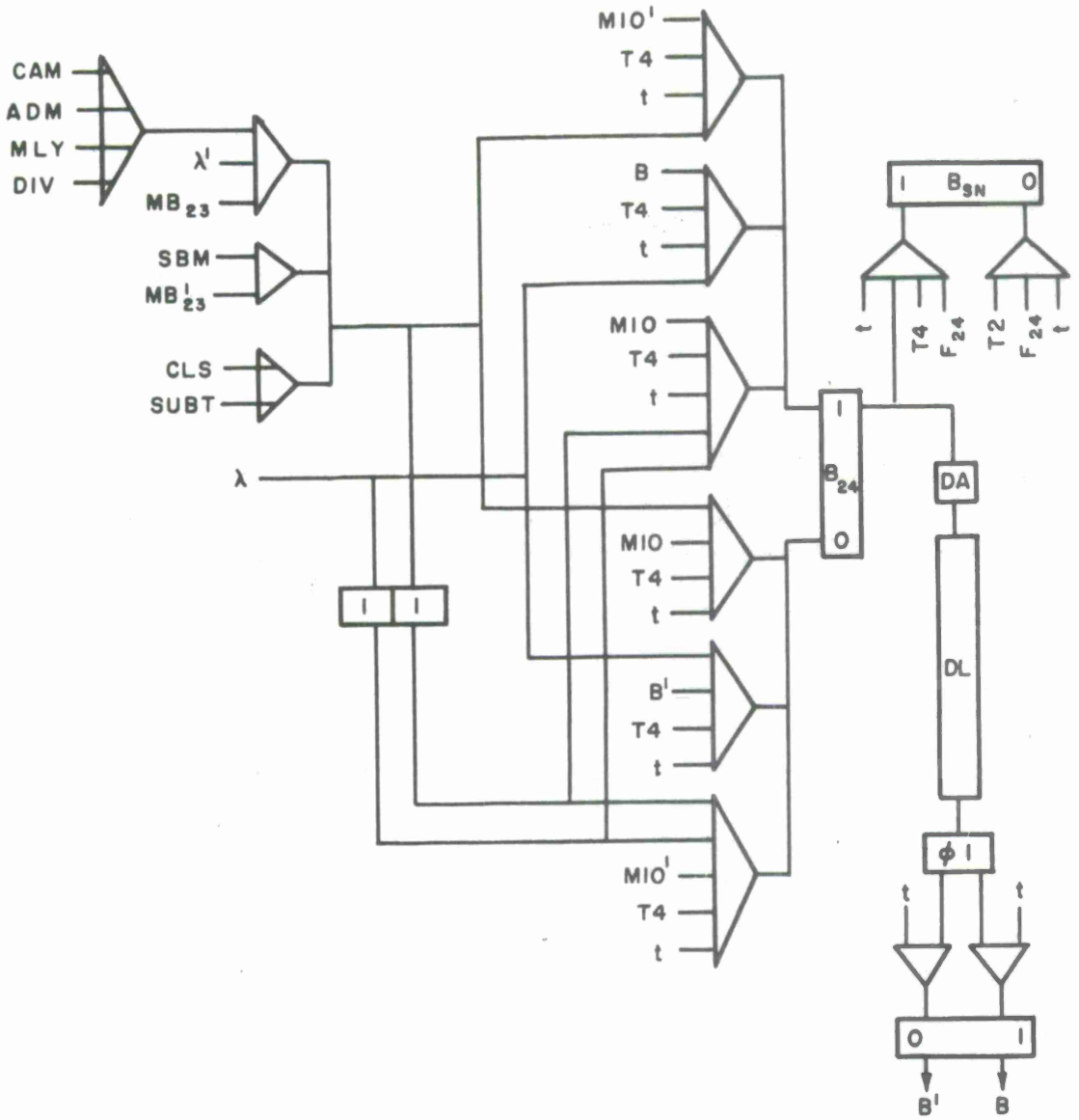


Figure 16. B Register

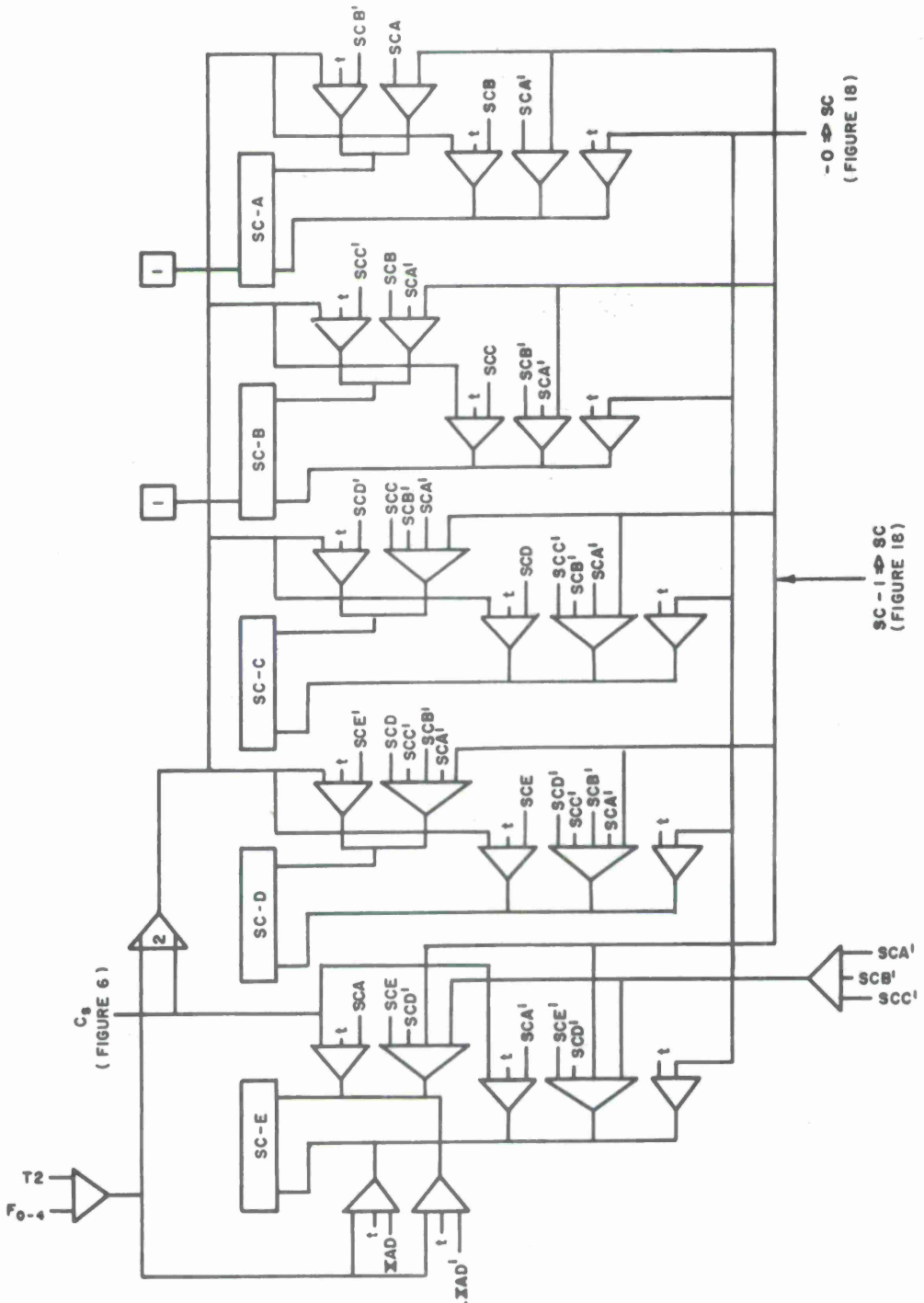


Figure 17. Shift Counter

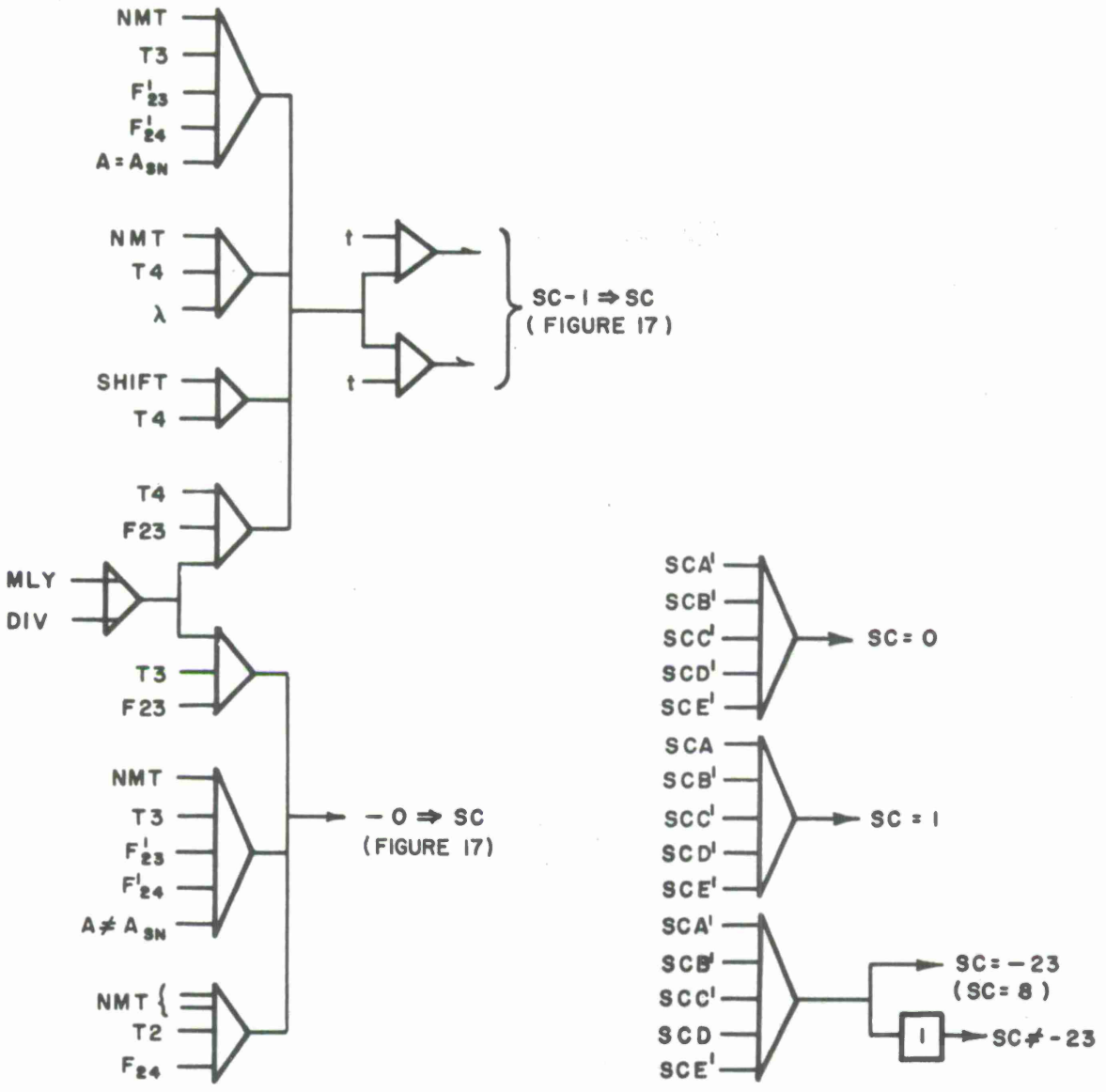


Figure 18. Shift Counter Controls

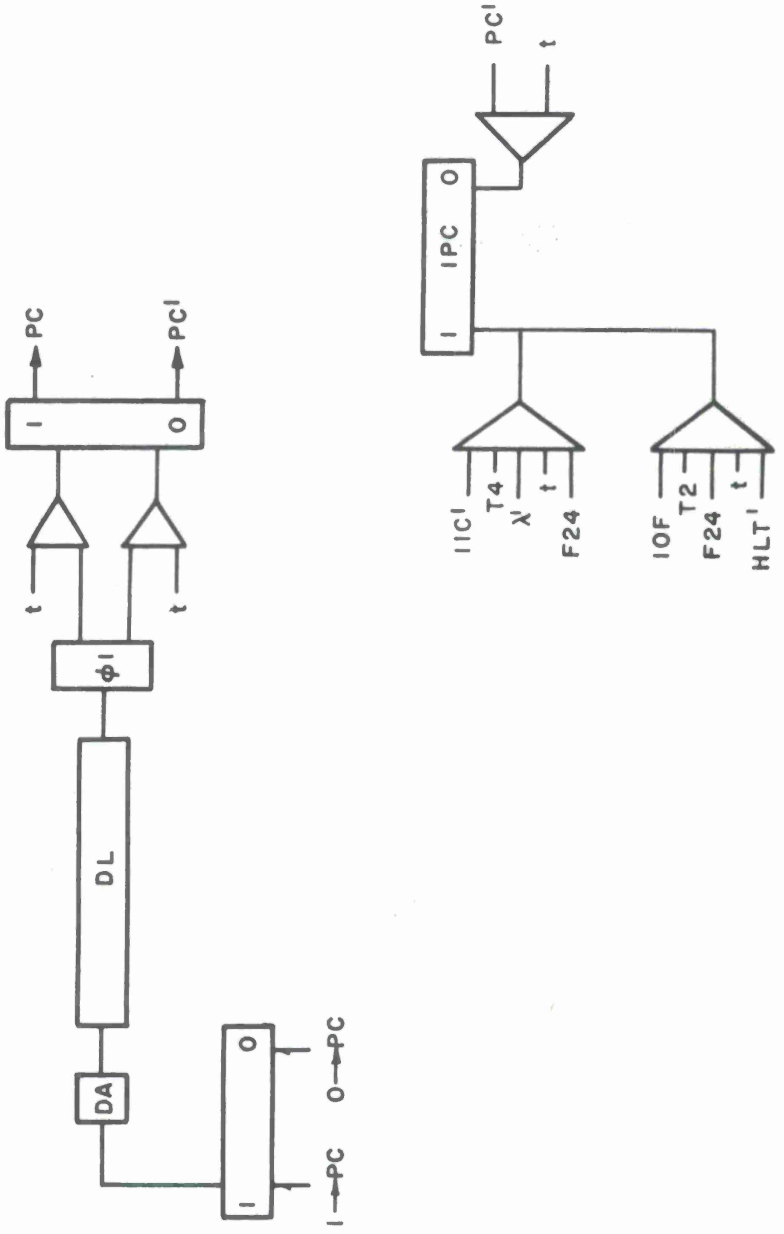


Figure 19. Program Counter

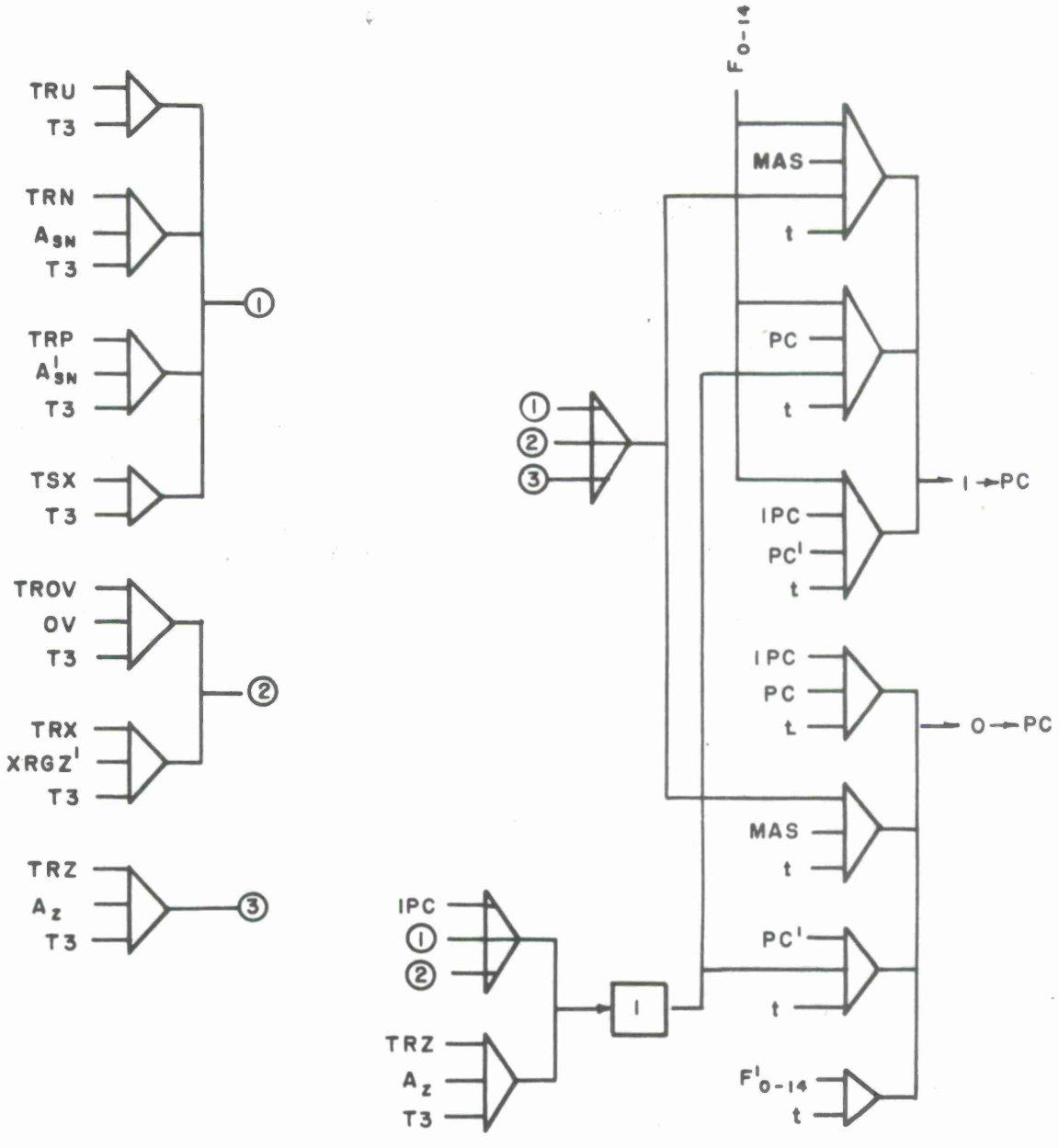


Figure 20. Program Counter Gates

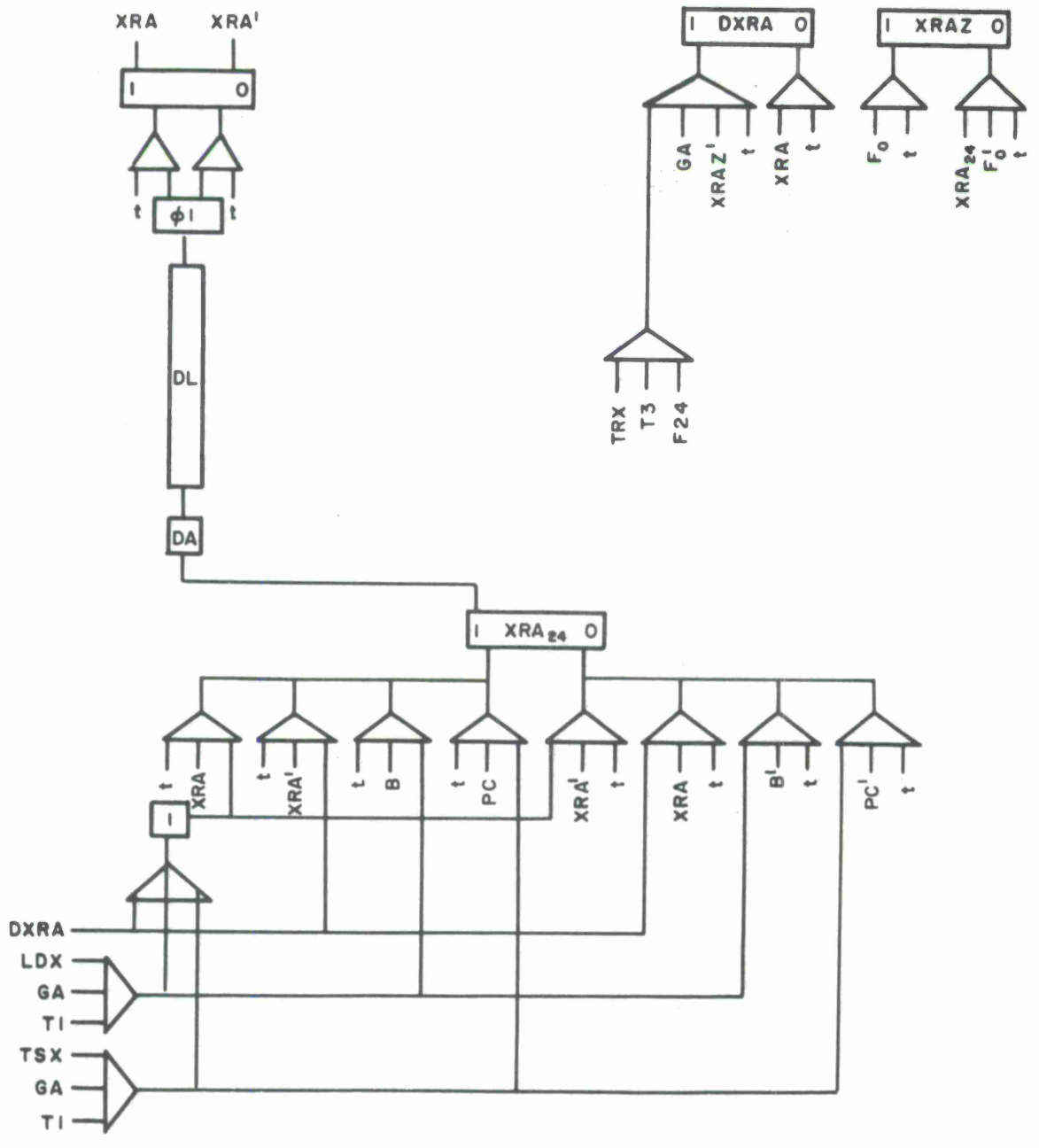


Figure 21. Index Register A

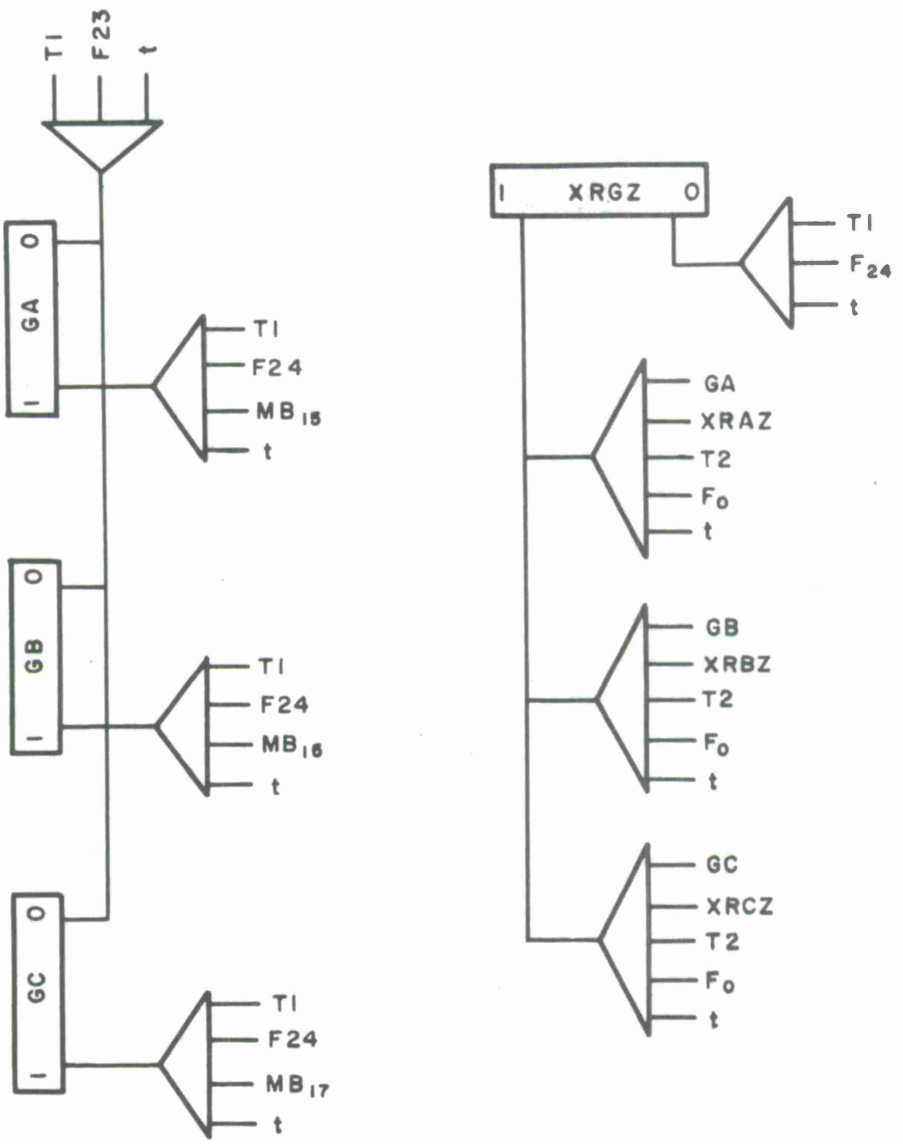


Figure 22. G Register

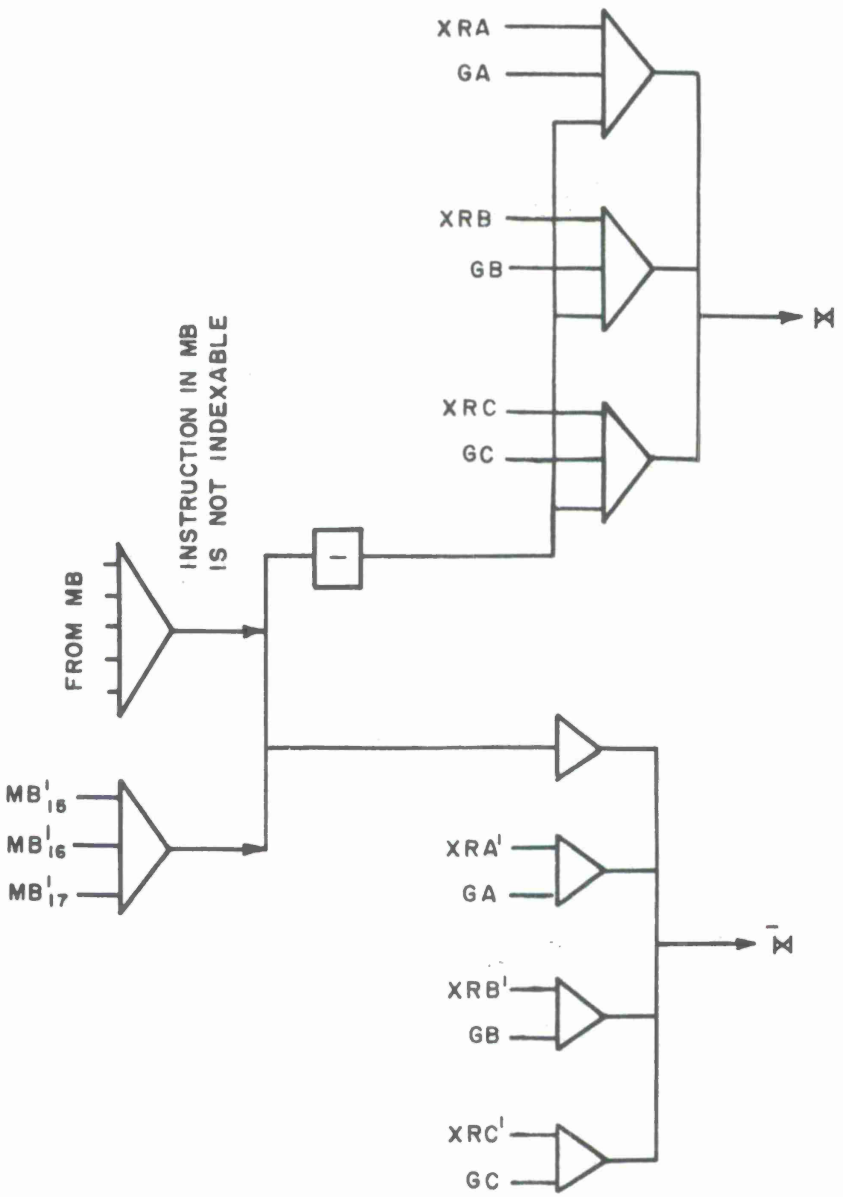


Figure 23. Index Selection

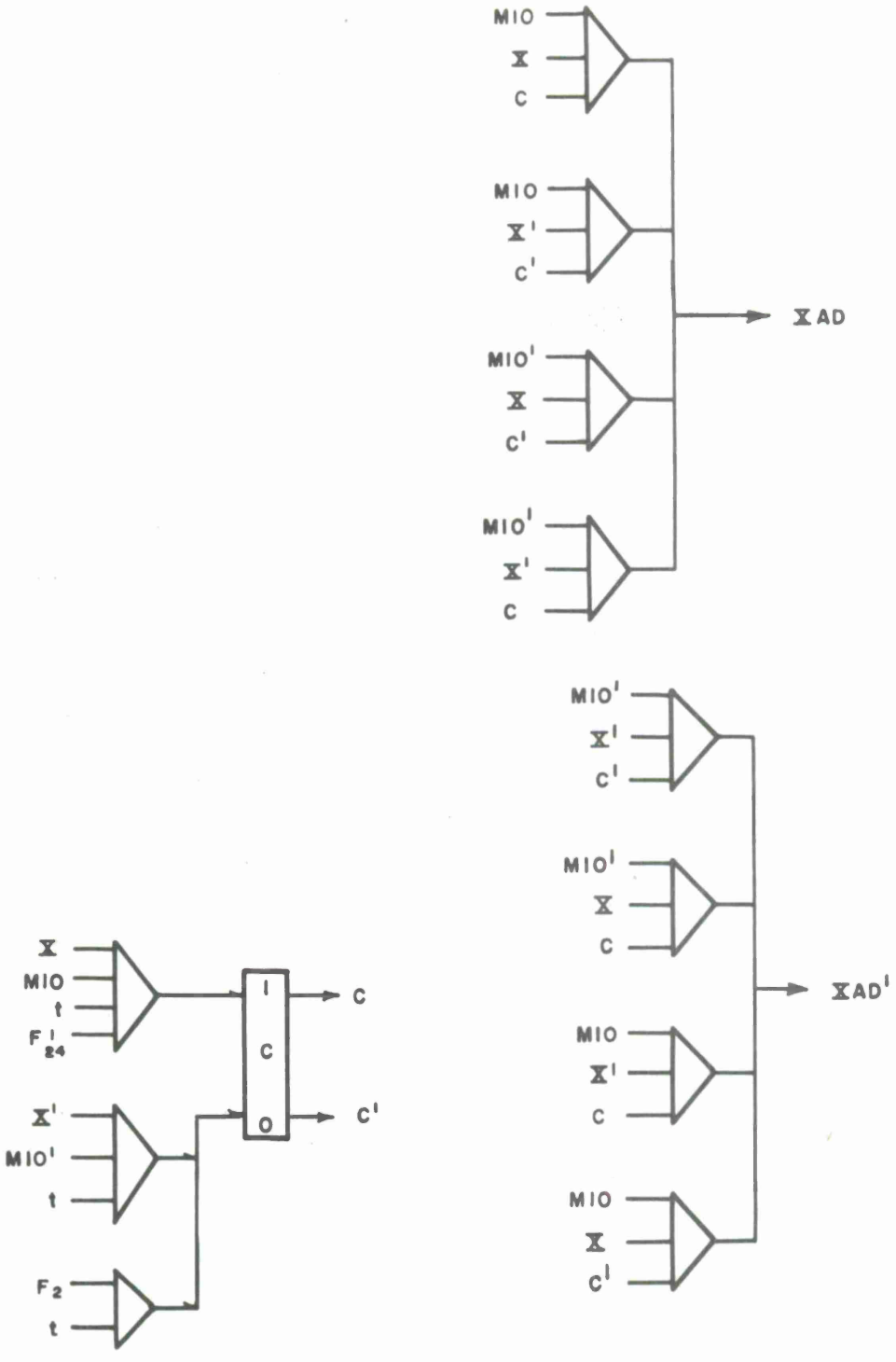


Figure 24. Index Adder (XAD)

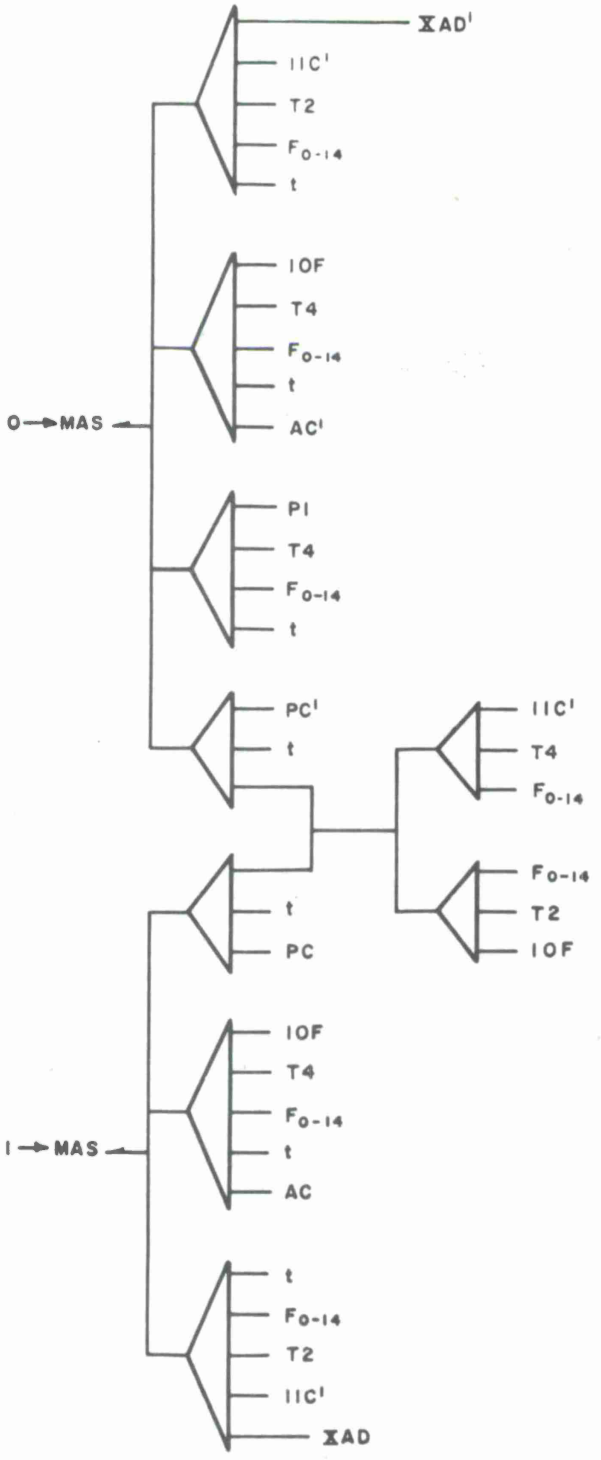


Figure 25. Memory Address Storage Gates

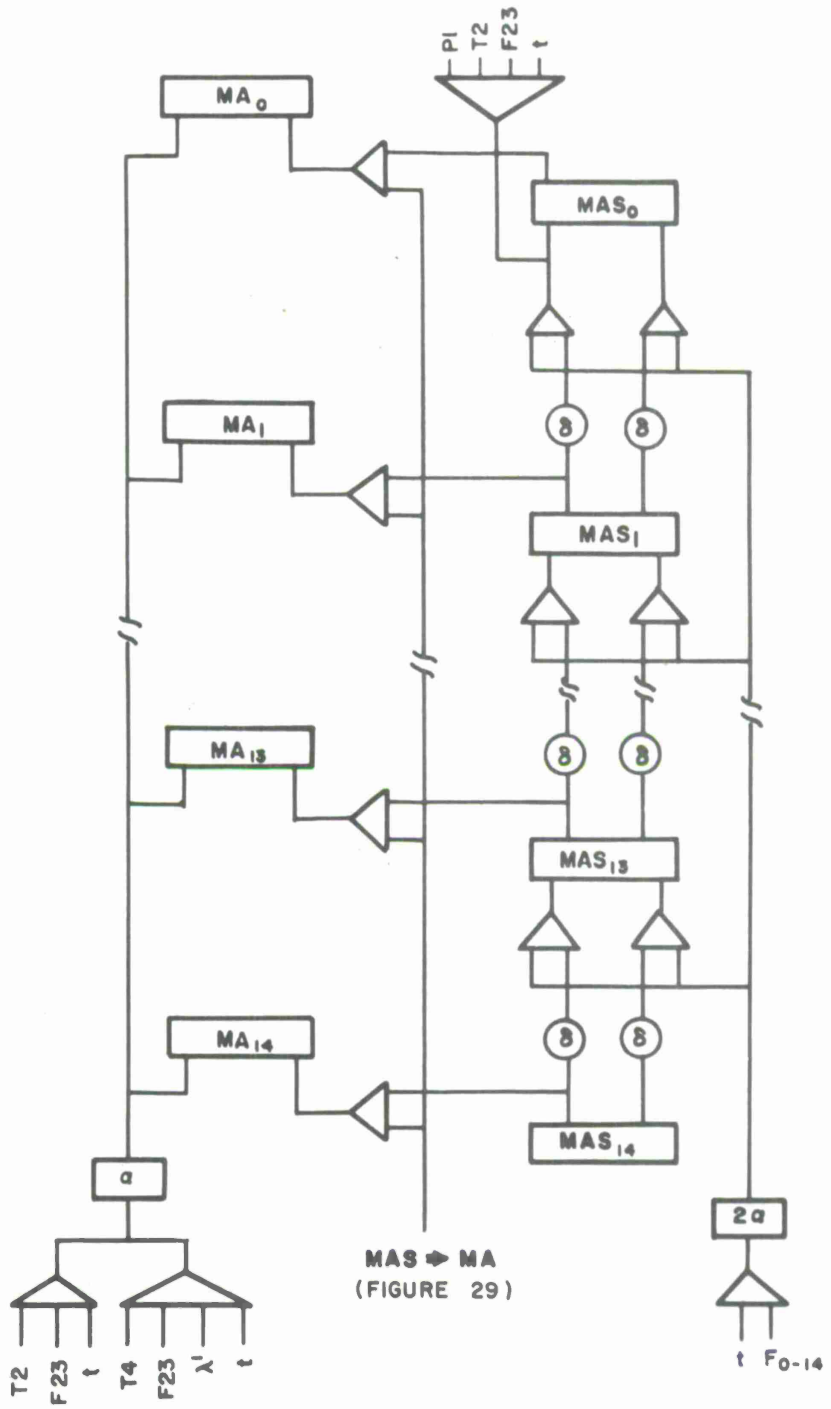


Figure 26. Memory Address Storage Register - Memory Address Register

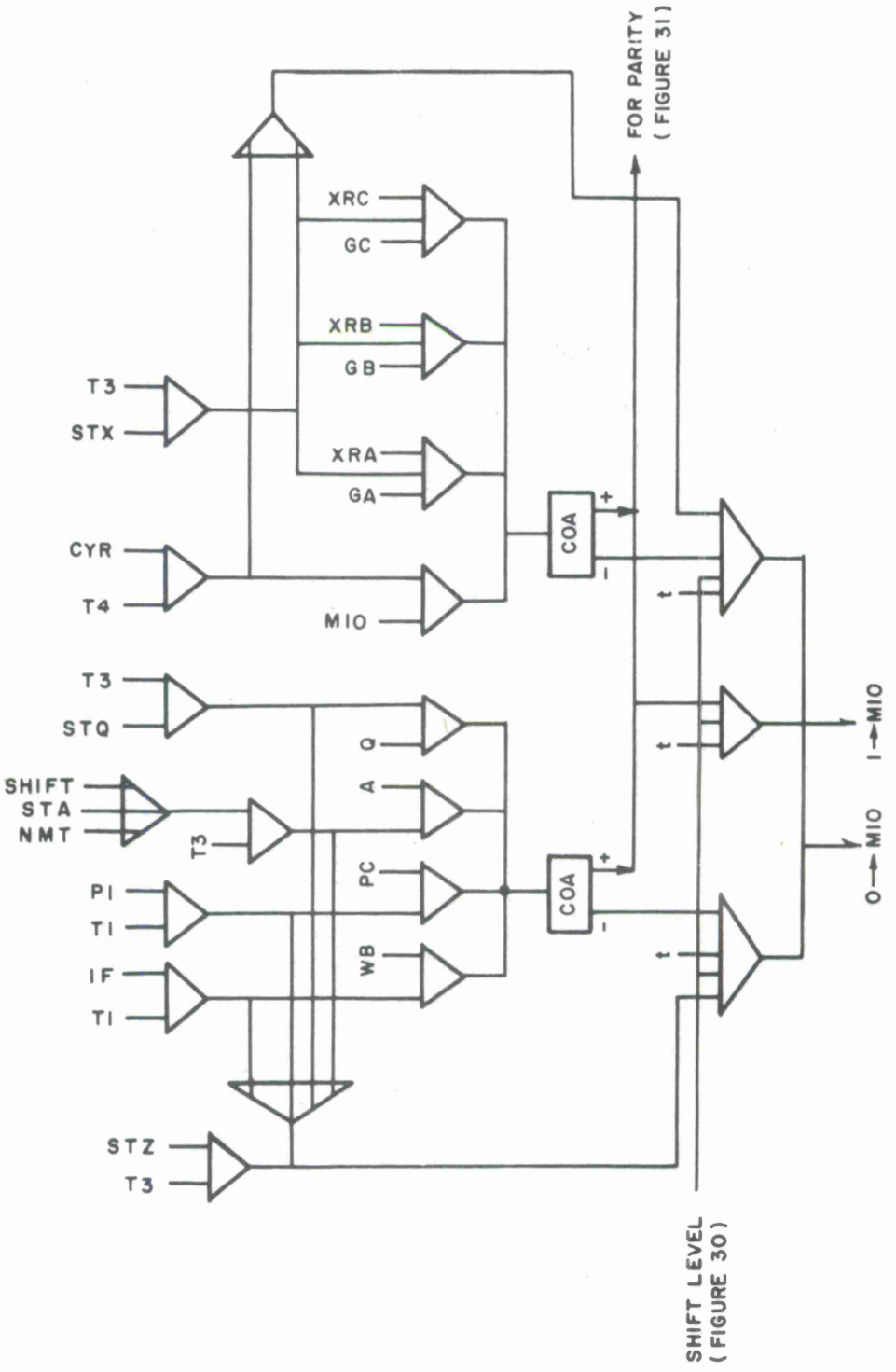
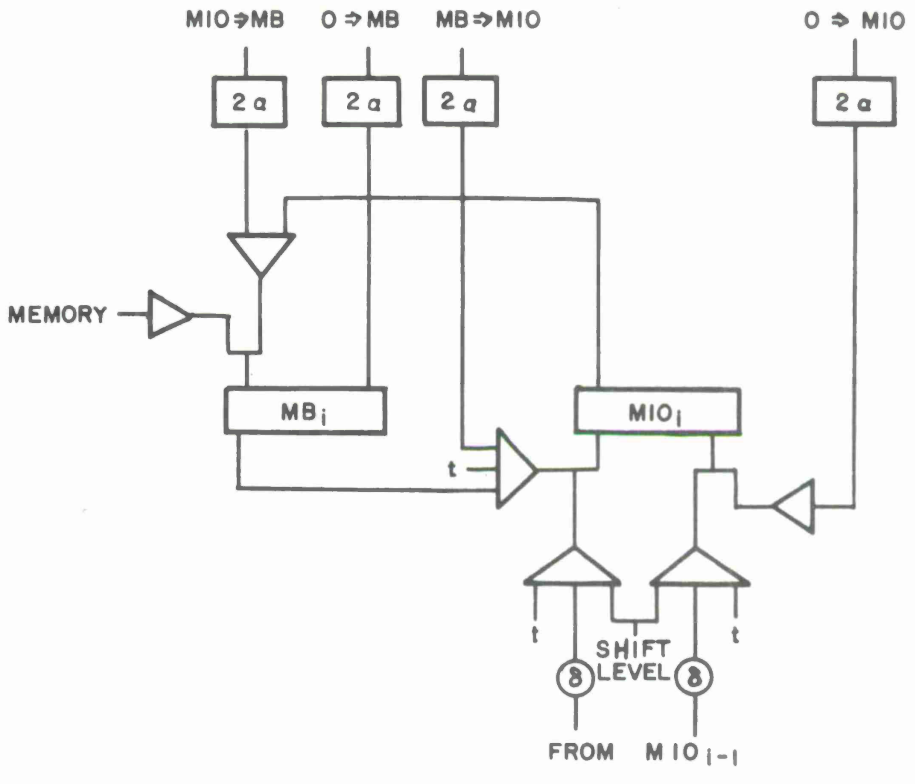


Figure 27. Memory Input-Output Register Input Gates



TRIPLE FF ON MIO$_0$

Figure 28. Memory Input–Output and Memory Buffer Register Stage (1 of 24)

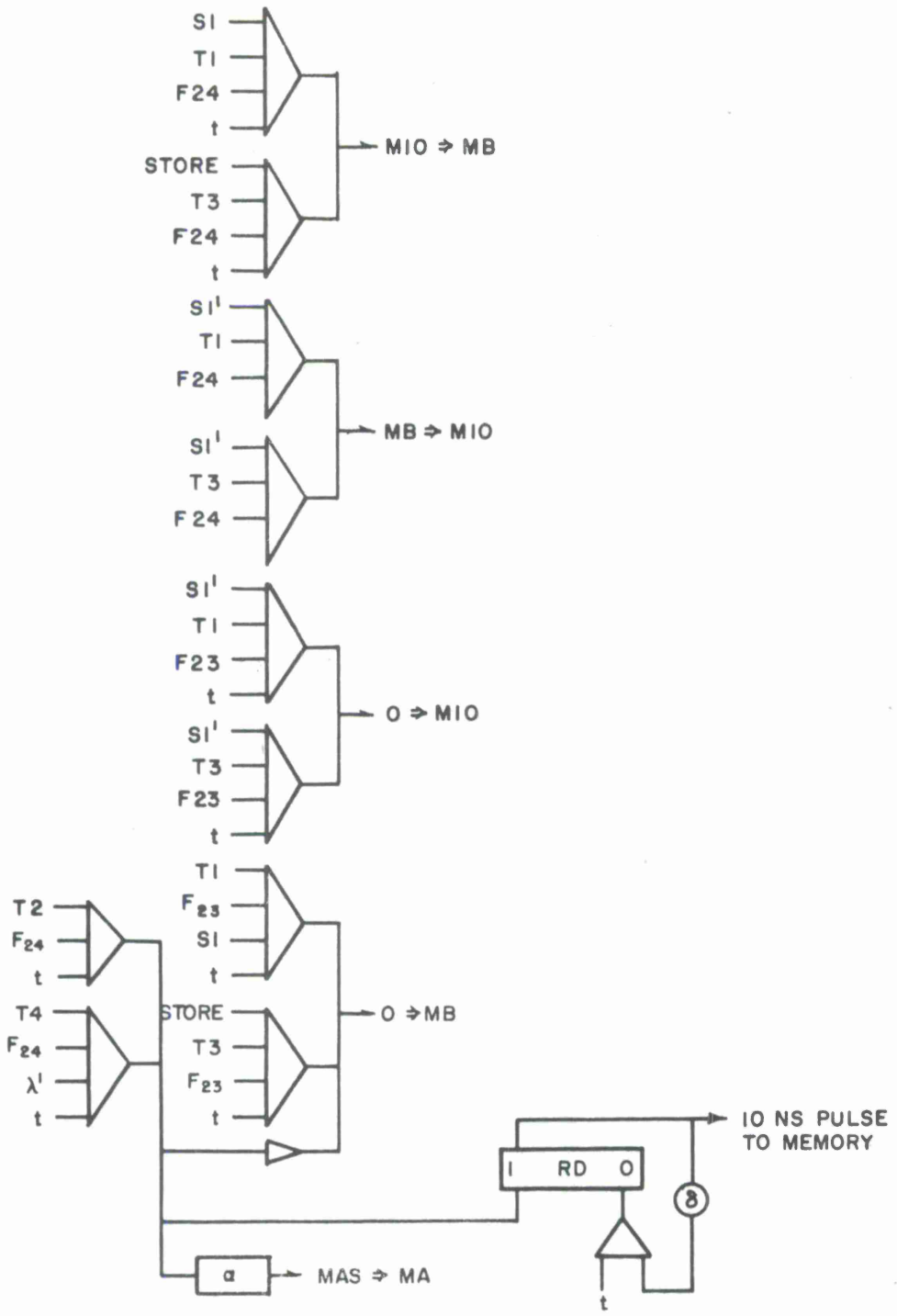


Figure 29. MIO-MB Controls

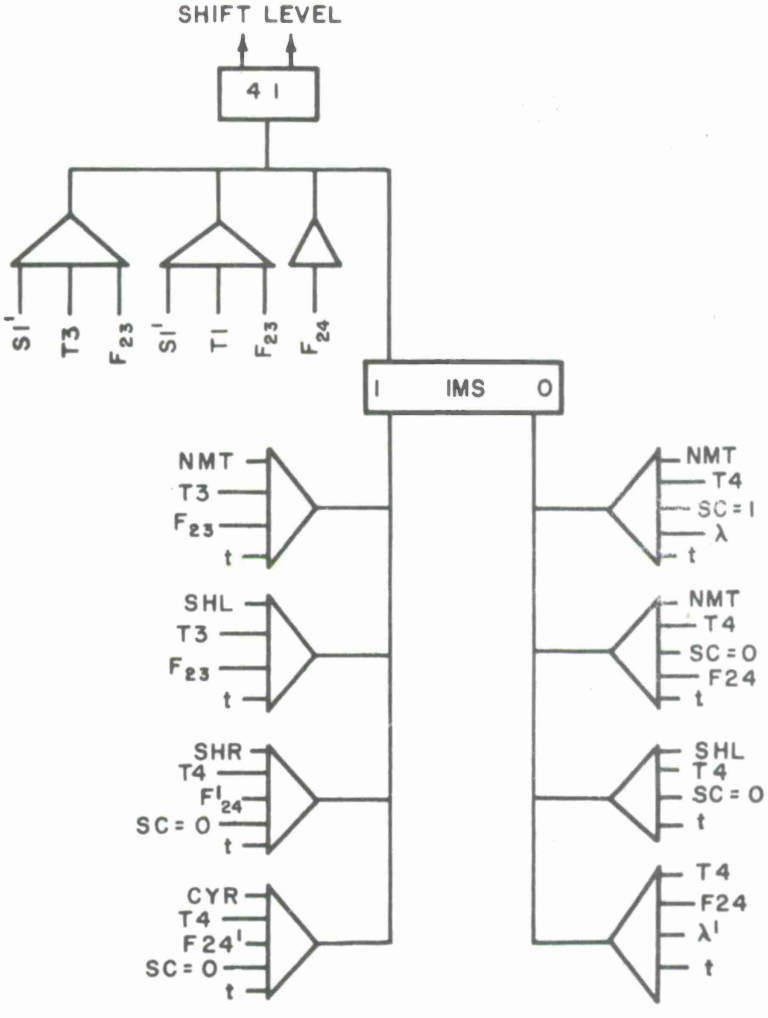


Figure 30. Memory Input-Output Register Shift Control

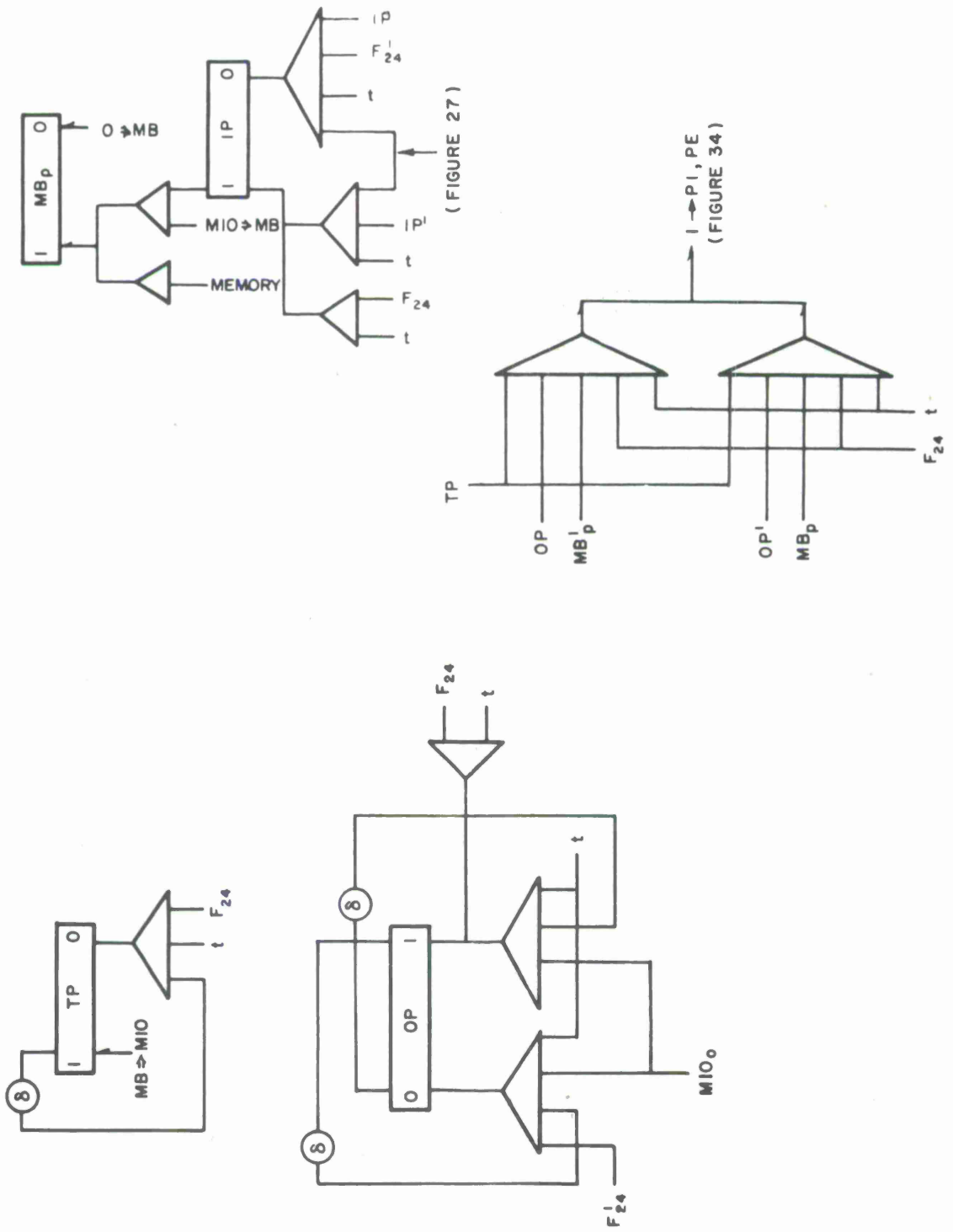


Figure 31. Parity

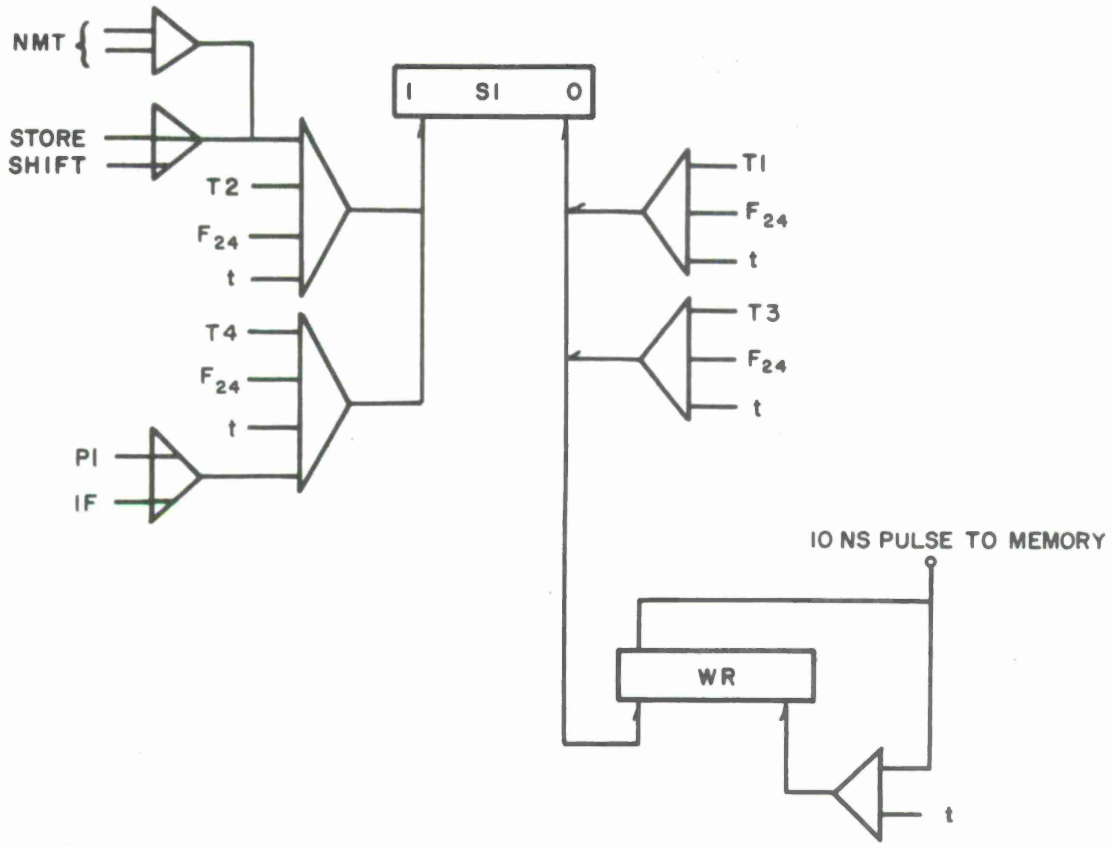


Figure 32. Memory Controls

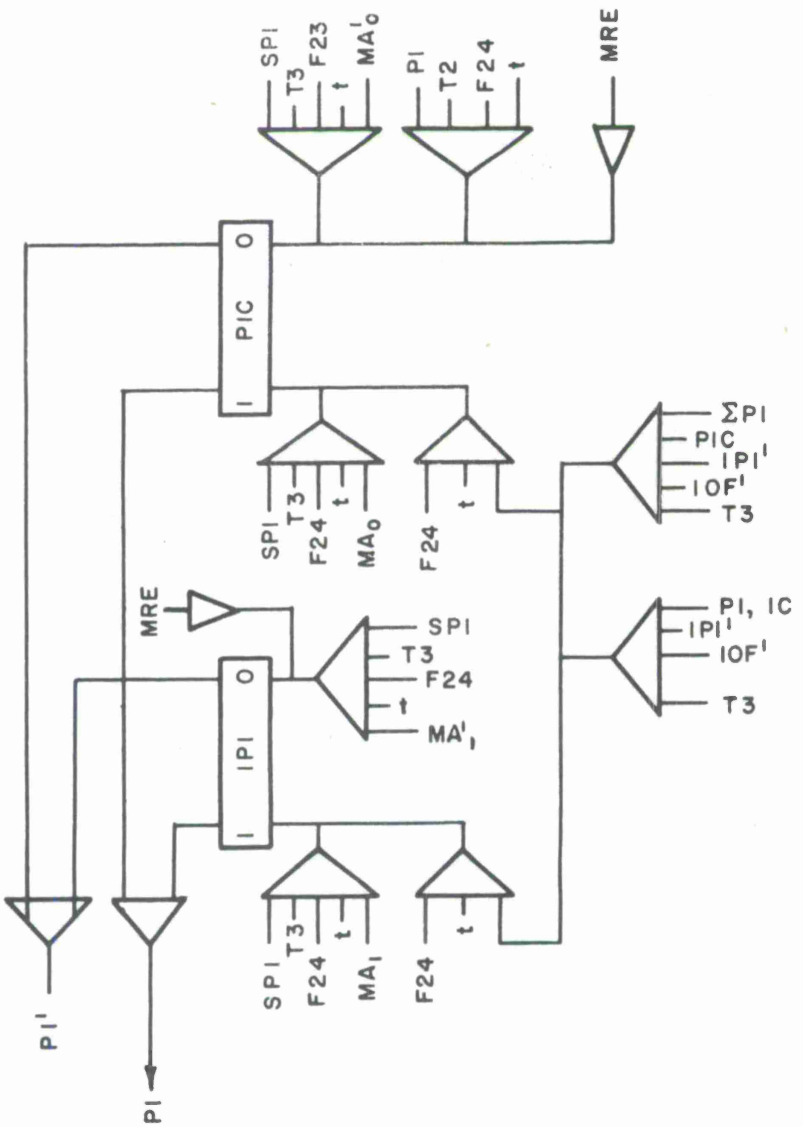


Figure 33. Program Interrupt Controls

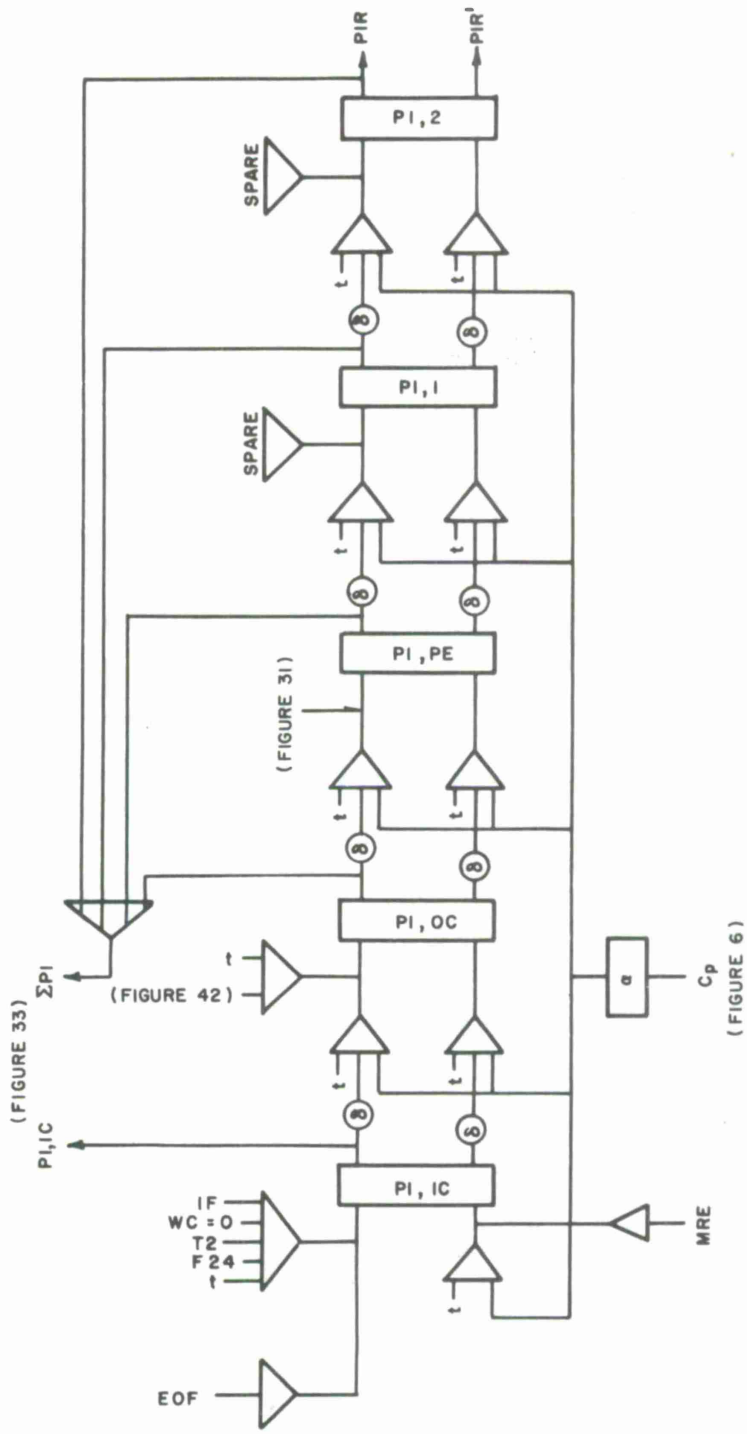


Figure 34. Program Interrupt Register

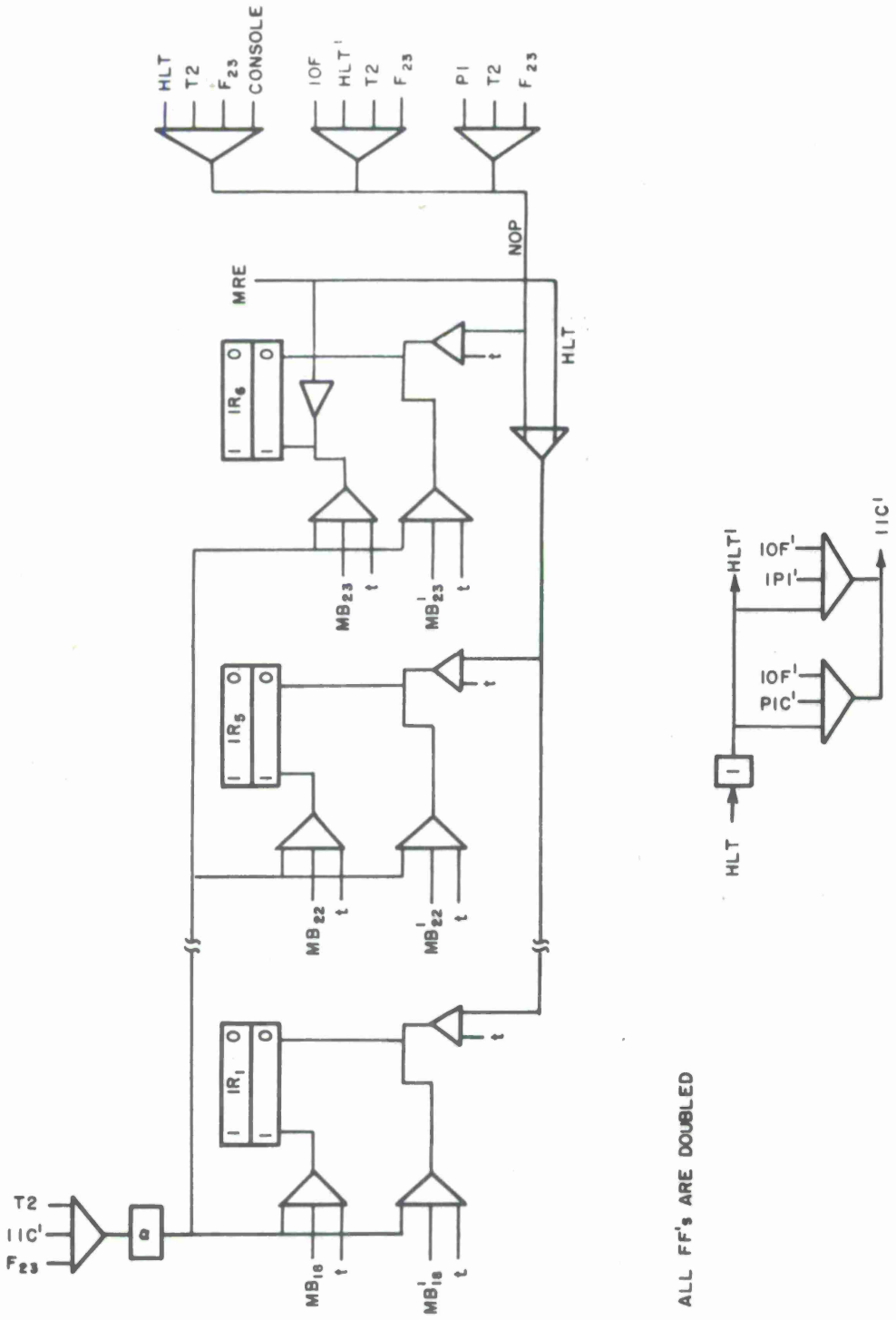


Figure 35. Instruction Register

33 INSTRUCTIONS ARE DECODED

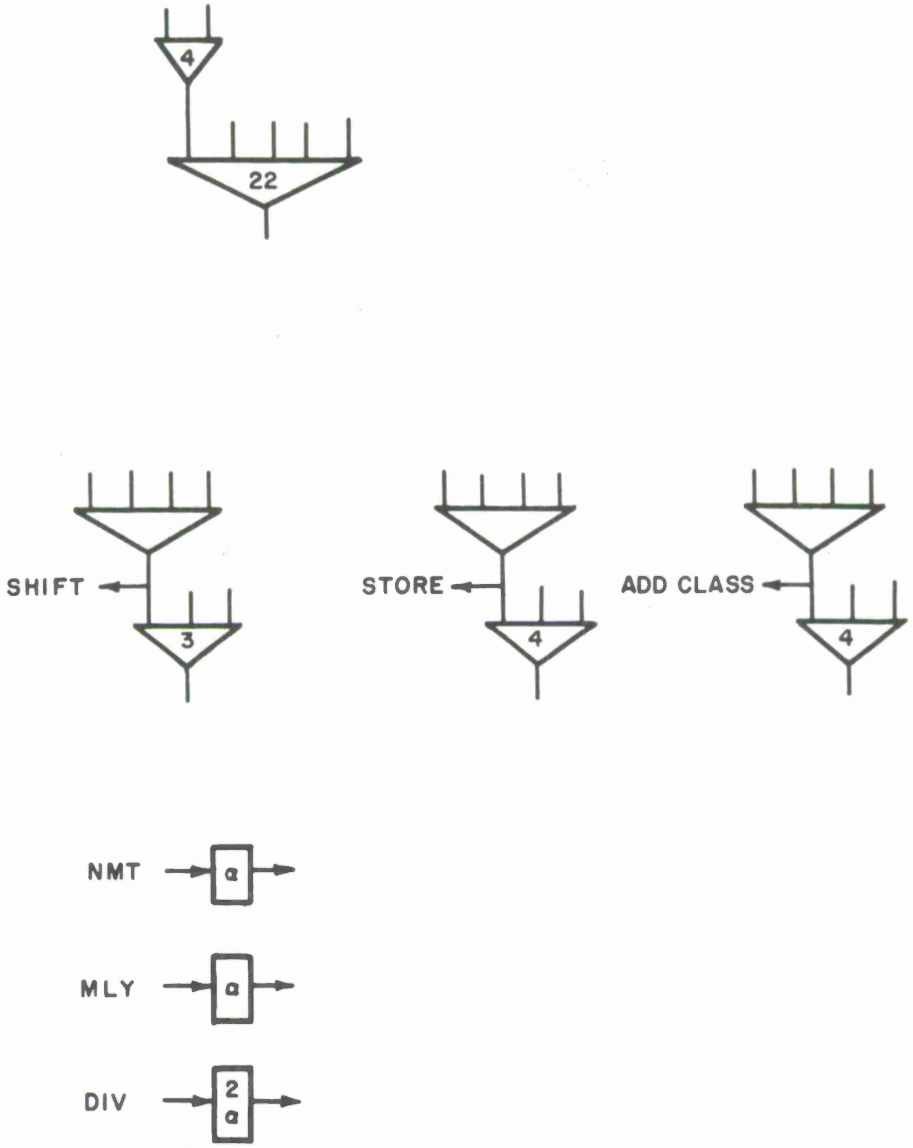


Figure 36. Decoder

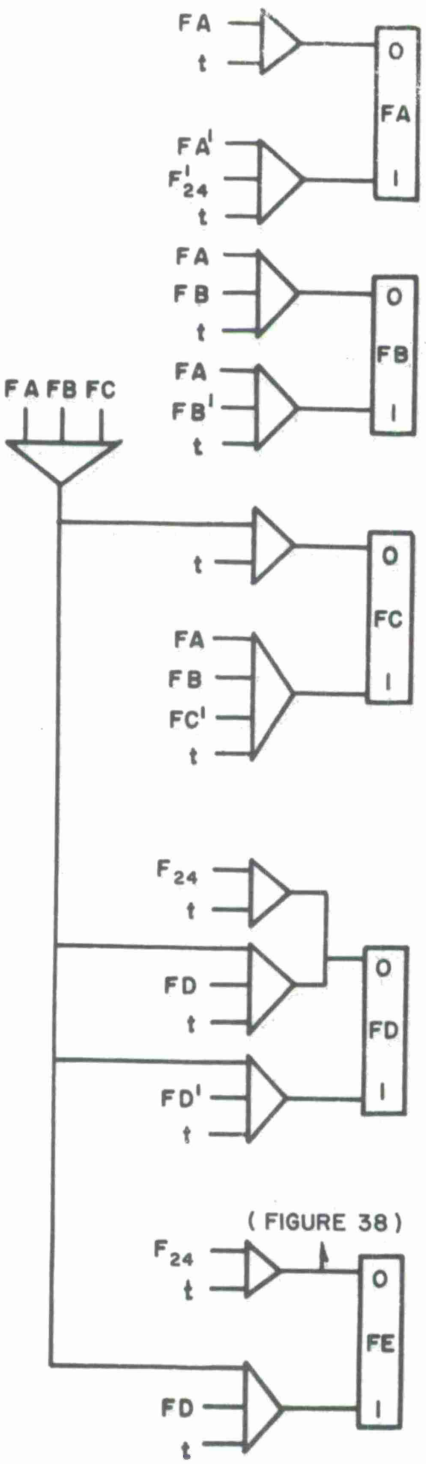


Figure 37. F Counter

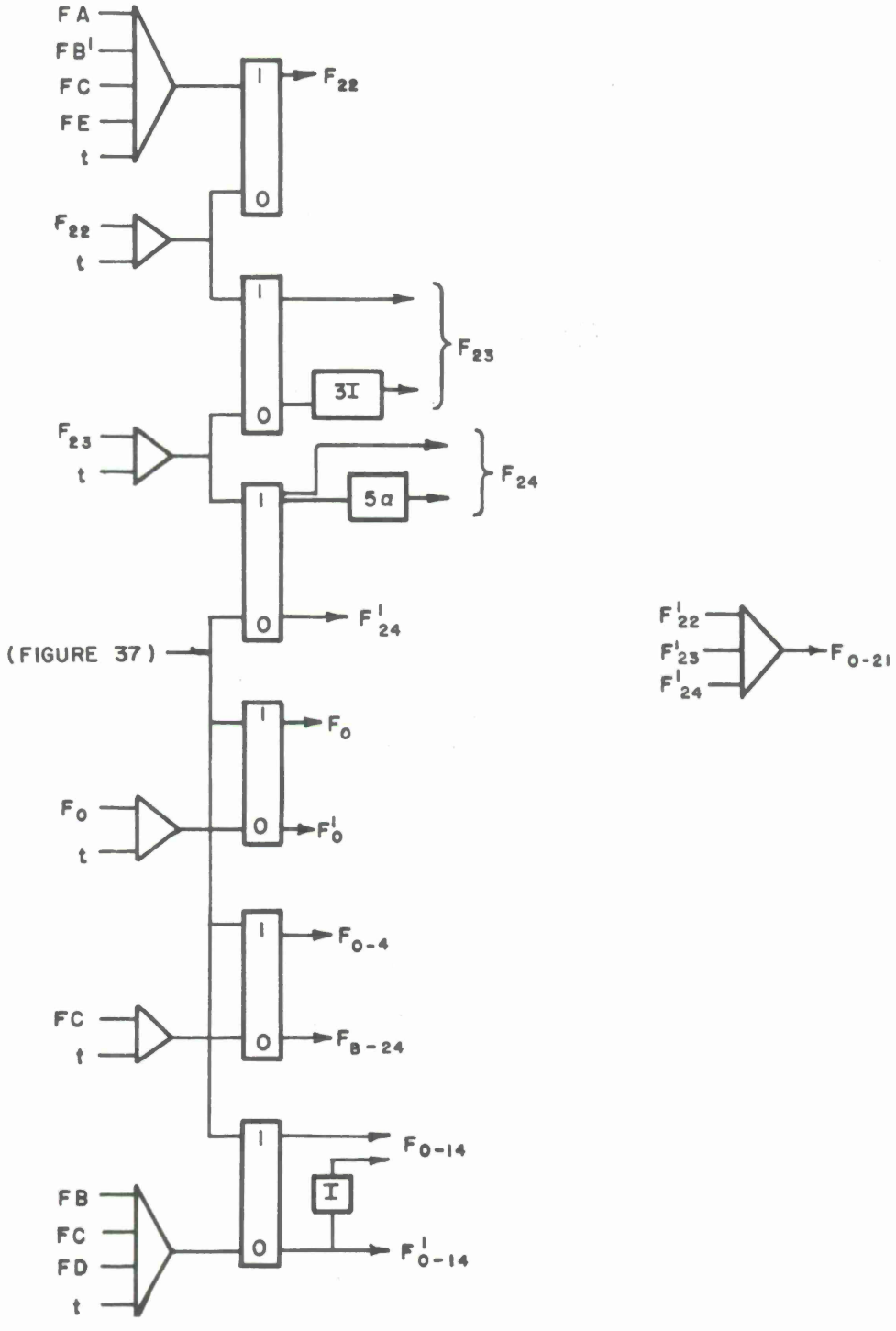
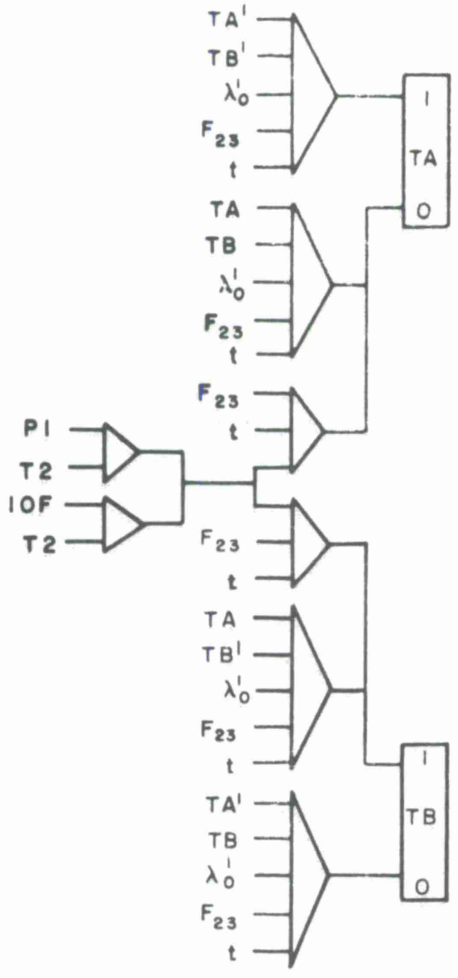
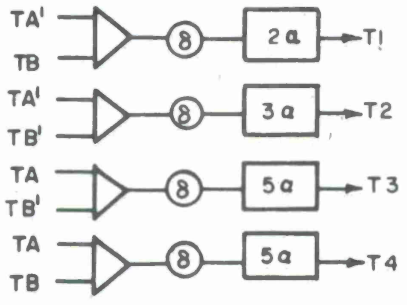


Figure 38. F Functions



T	A	B
1	0	1
2	0	0
3	1	0
4	1	1



DELAY TRIMMED SO THAT T LEVEL RISES 12.5 NS AFTER $(F_{23})(t)$ PULSE

Figure 39. T Counter

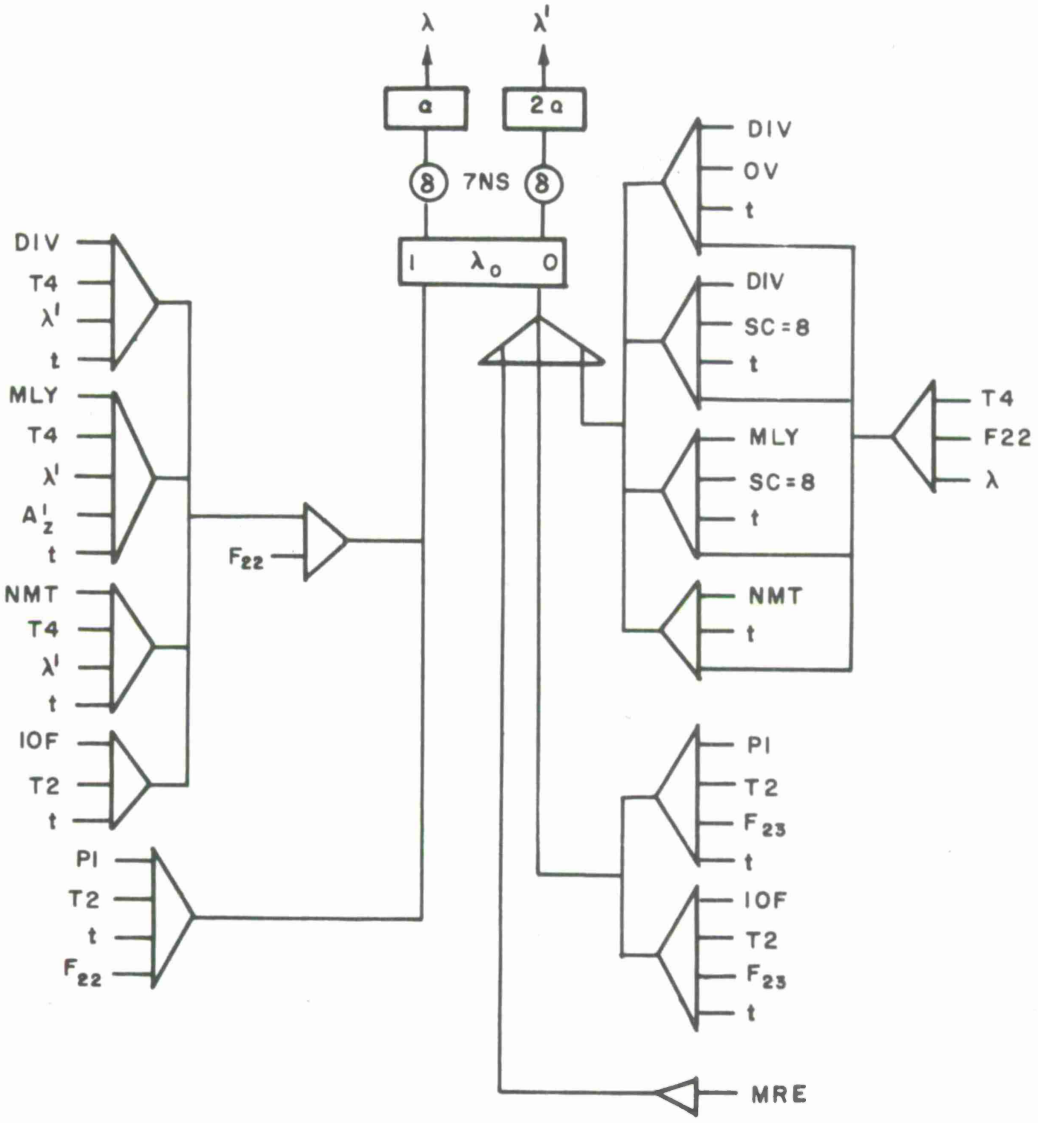


Figure 40. Lambda Flip Flop

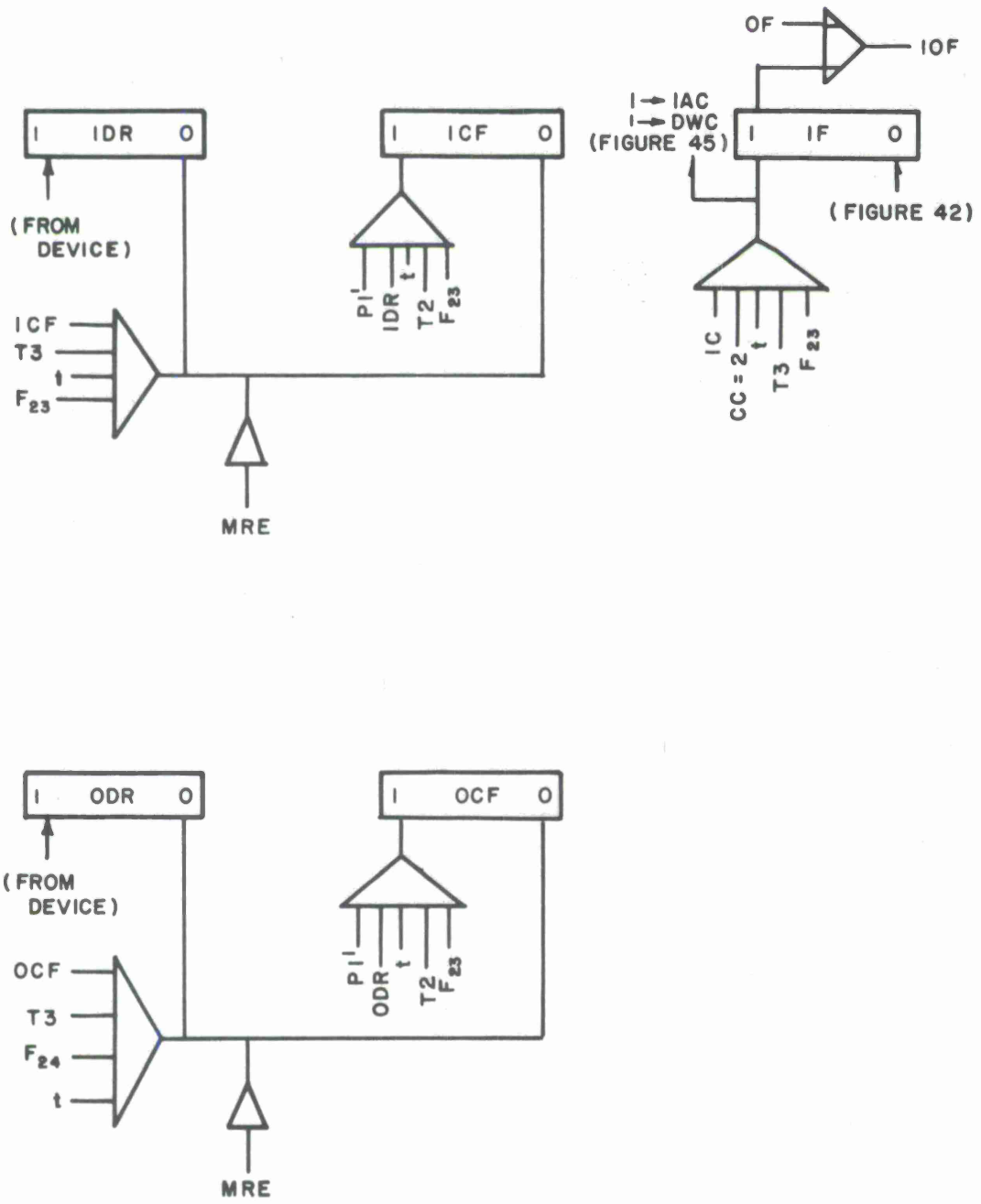


Figure 41. I/O Controls

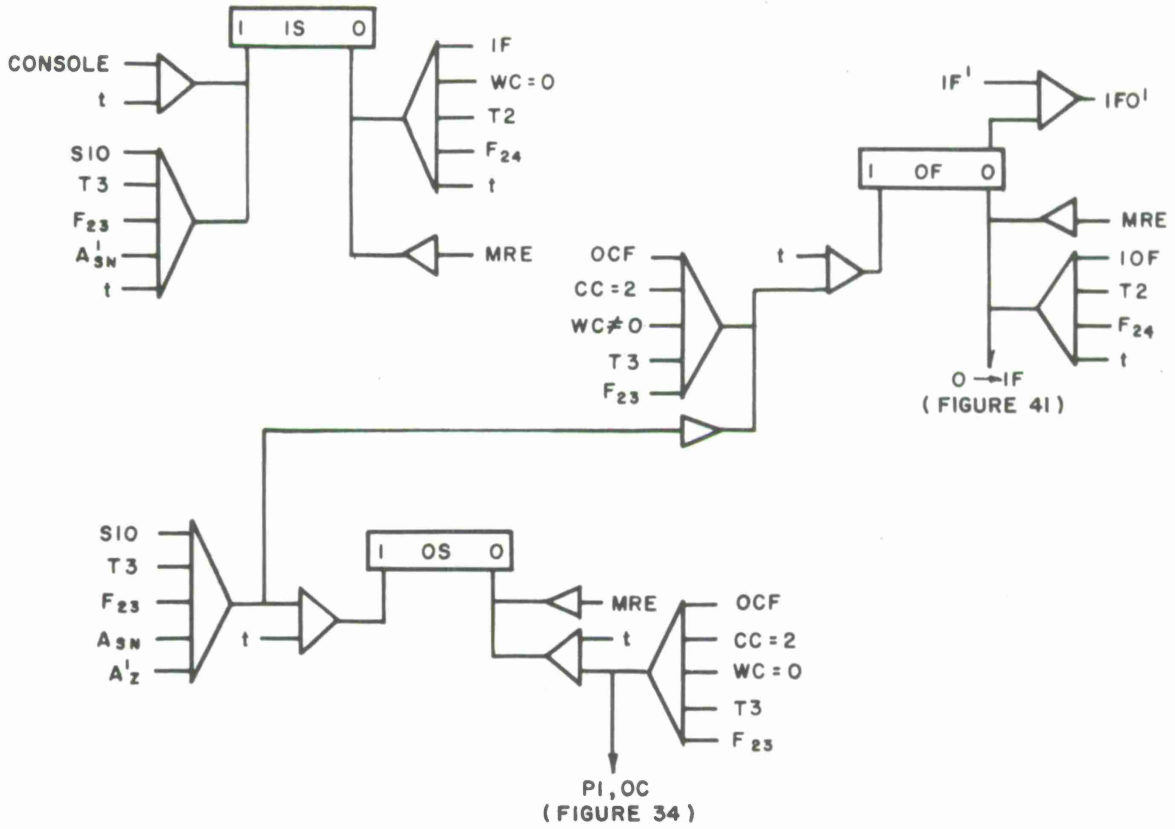


Figure 42. I/O Controls

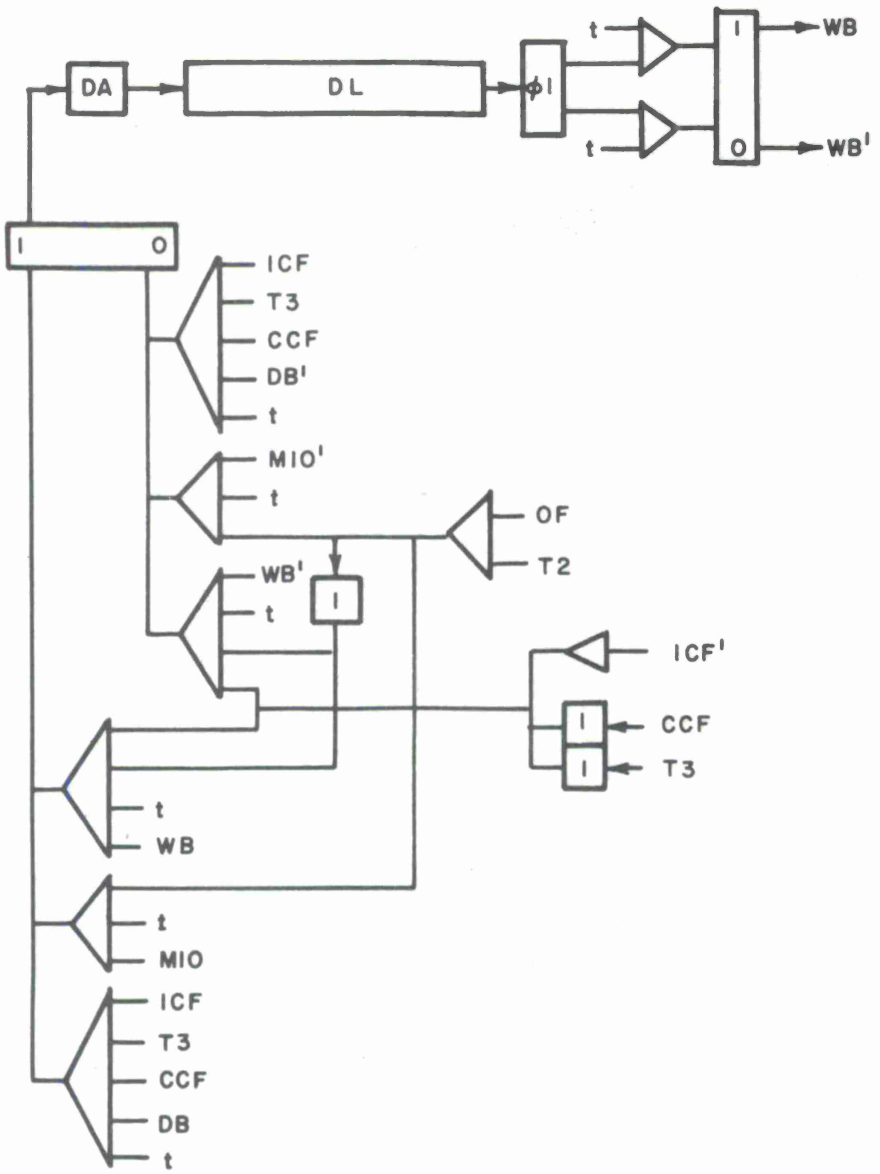


Figure 43. Word Buffer Register

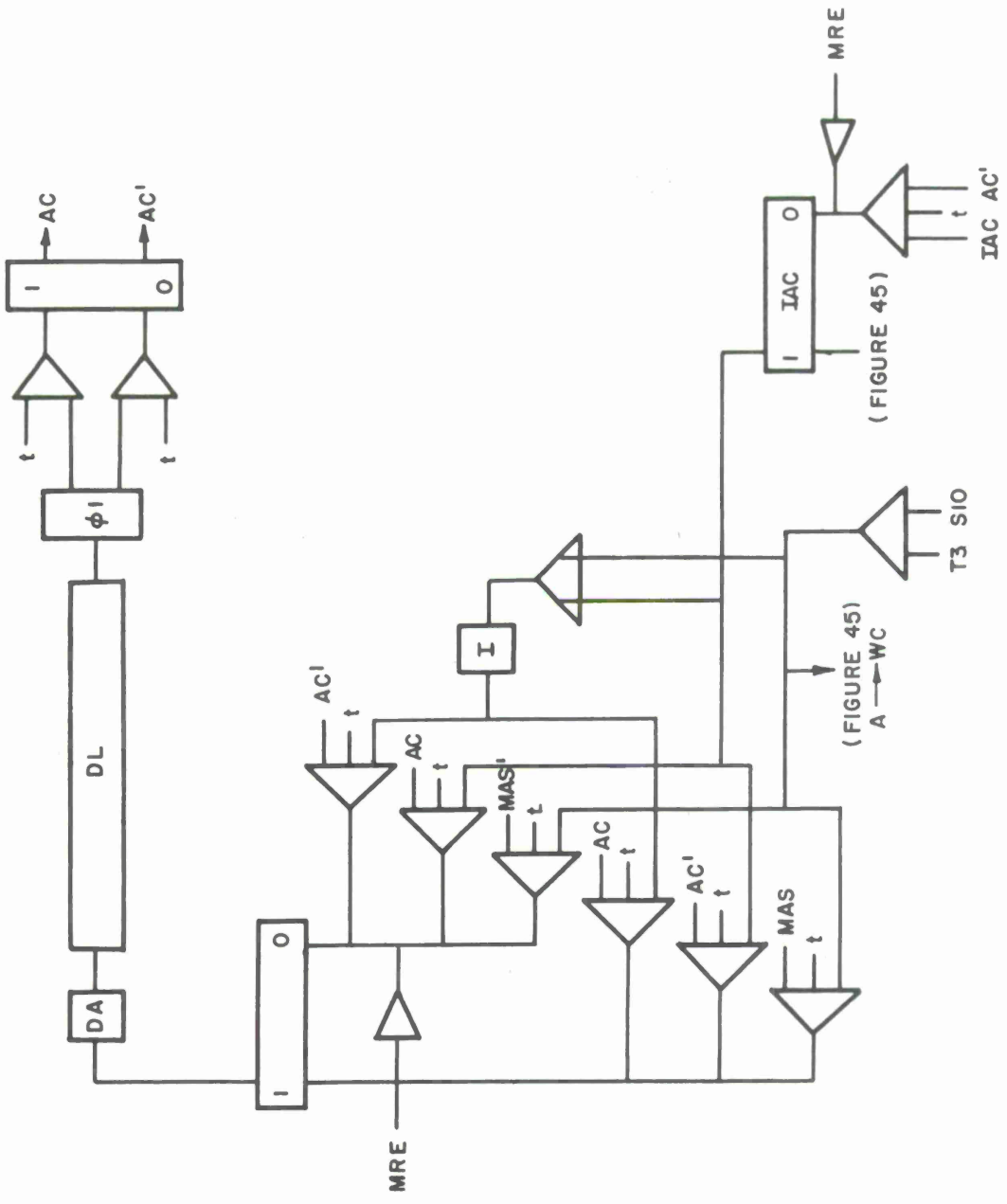


Figure 44. Address Counter

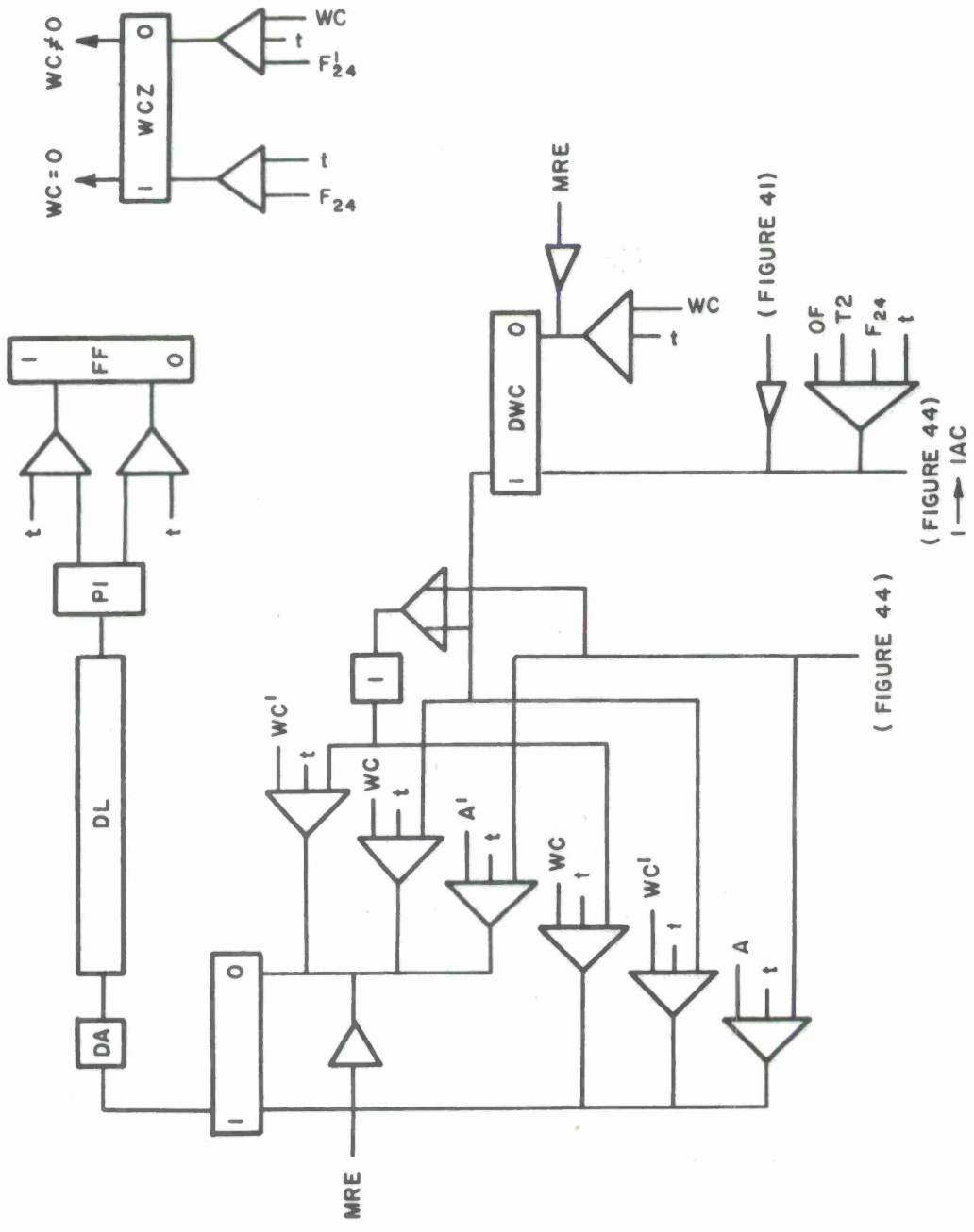


Figure 45. Word Counter

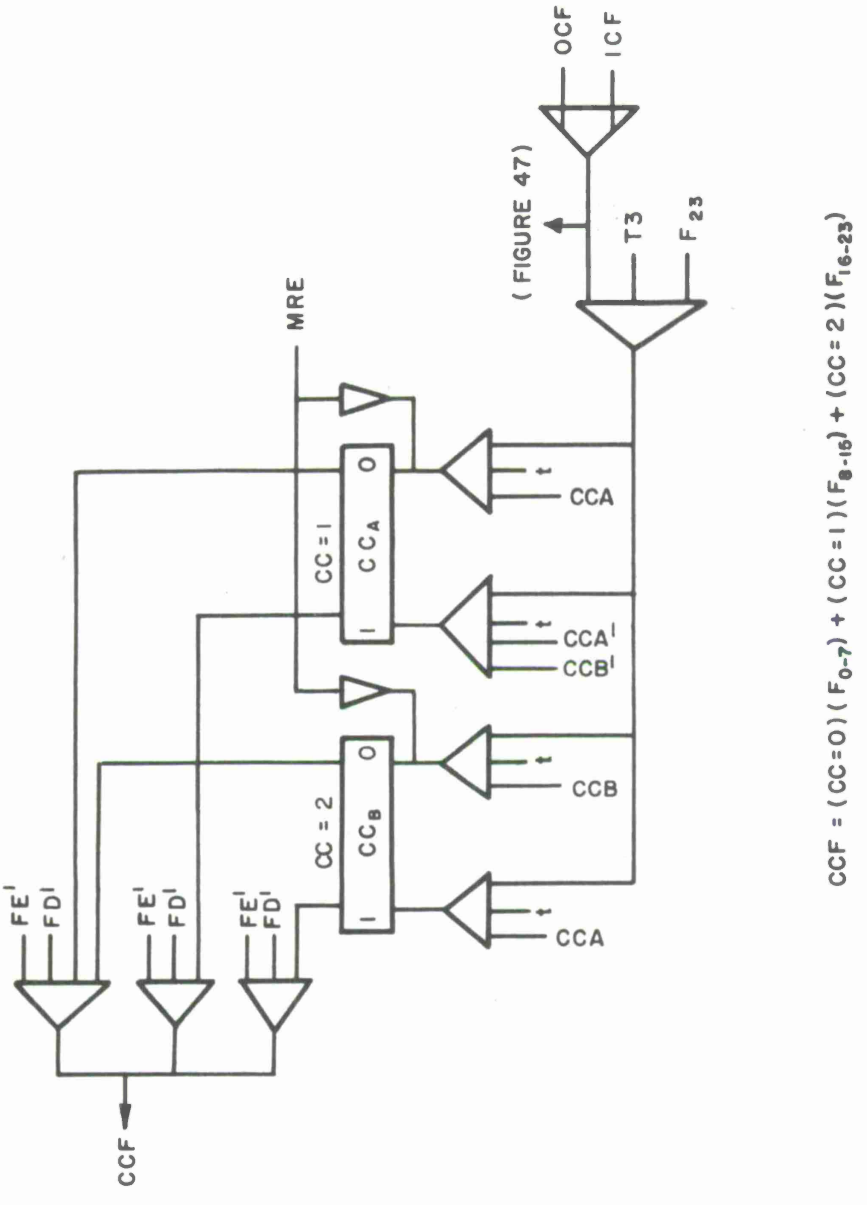


Figure 46. Character Counter

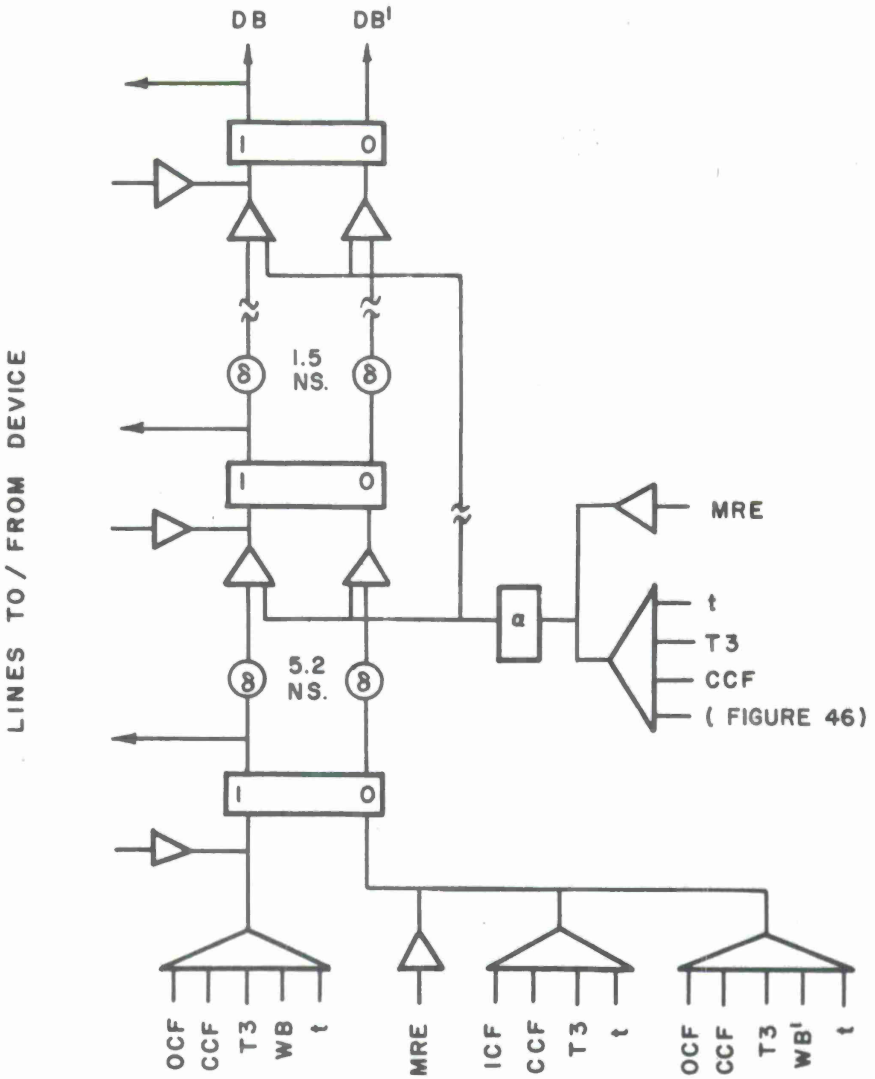


Figure 47. Device Buffer

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* The MITRE Corporation Bedford, Mass.	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Logical Design for Fast Serial Computer

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

N/A

5. AUTHOR(S) *(Last name, first name, initial)*

Enderton, H. B.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 1965	78	0

8a. CONTRACT OR GRANT NO. AF19(628)-2390 b. PROJECT NO. 508 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) ESD-TR-65-81 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* W-07189

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	Directorate of Computers. Electronic Systems Division L. G. Hanscom Field, Bedford, Mass.

13. ABSTRACT

The detailed logical design is given for a serial digital computer using a 0.5-microsecond magnetic memory, 100-mc logical circuits, and one-word delay lines. The computer performs most instructions in 1 microsecond. A list is given of the amount of hardware used.

DD FORM 1 JAN 64 1473

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
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